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RETAINING WALLS.*

Retaining walls are adopted as a necessary expedient in railway and other practice, often under very peculiar circumstances, as when there is not sufficient room for the slope of the embankment; it being sometimes perched high on a steep mountain's side, and where it would have been hardly possible to construct a railway at all, except by securing it with a massive wall occupying comparatively little space.

When it is also remembered how fearfully terrible any accident would be if it was to occur in such a dangerous situation—if by any erroneous calculation or mistaken judgment on the part of the engineer sufficient strength had not been given to the work, the wall which was to have supported the embankment, suddenly giving way, falling over into a deep ravine or chasm, a large portion of the embankment going with it, and, it may be also, a passing train—there can be no doubt but that the nature of the material of which the embankment is to be made should be understood, and the best form and requisite dimensions for the wall should be well considered and accurately ascertained beforehand, so that it may be amply strong enough.

At the same time that the wall should be made perfectly secure, it is also often desirable that any unnecessary excess of strength should not be given to it, and so thereby avoid increasing its cost considerably, as the value of work is often very much enhanced when it has to be executed in such inaccessible situations as before mentioned, where all the materials for building it may have to be brought from a great distance.

The engineer thus may be at a loss to determine of what size a retaining wall should be built, so as to be safe against all contingencies that can occur, and yet also to be economical.

In many cases there have been failures which may have arisen from not correctly ascertaining beforehand how the material of which the embankment is composed will be affected by the alternations of wet and dry weather before it is thoroughly consolidated, and the precise angle at which its slope will stand in either case, thereby causing a considerable difference in its pressure against the wall.

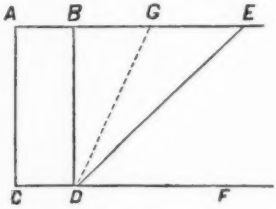
A retaining wall also, as in the case of the wing-walls of a bridge, being built at the same time that the embankment is being filled in behind it, has often to withstand then a considerable greater pressure than it will have to do afterwards when the embankment is settled; this also perhaps when its work is green, and not prepared to resist the pressure intended for it. Sometimes also the punning of the material behind it has (as is often the case) not been done effectually, and a heavy rain changes the dry earth or clay into a wet sludge, causing it to swell considerably.

It therefore being such an important point in railway construction, it would no doubt be very desirable if some simple form of calculation were used, not only strictly

* Surcharged and Different Forms of Retaining Walls, by James S. Tate, C. E. London: E & F. N. Spon.

accurate, but easily adapted to any circumstances that may occur. In the case of a wall where the embankment is level with its top the calculation of the pressure is well known, being very simple, and is as follows:

Let B D be the back of a retaining wall, D E the natural slope of the embankment,



then if we bisect the $\angle$ B D E by the line D G, B D G is the portion of the embankment supported by the retaining wall.

Now the weight of B D G : pressure of its weight against the wall : : B D : B G : : H : H tang. $\angle$ B D G. The weight of

$$BDG = \frac{H}{2} \times BG \times W =$$

$$\frac{H}{2} \times H \text{ tang. } \angle BDG \times W =$$

$$H^2 \times \frac{\text{tang. } \angle BDG}{2} \times W.$$

Pressure of weight of

$$BDG = H^2 \times \frac{\text{tang. } \angle BDG}{2} \times W \times \text{tang. } \angle BDG$$

$$= H^2 \times \frac{\text{tang.}^2 \angle BDG}{2} \times W.$$

Moment of pressure of weight of

$$BDG = H^2 \times \frac{\text{tang.}^2 \angle BDG}{2} \times W \times \frac{H}{3}$$

$$= \frac{H^3}{6} \times \text{tang.}^2 \angle BDG \times W,$$

and the double of this moment for stability

$$= \frac{H^3}{3} \times \text{tang.}^2 \angle BDG \times W.$$

In the case of a vertical wall, as A B C D, its weight = W H B, and the moment of its weight

$$= \frac{W H B^2}{2};$$

then for equilibrium,

$$\frac{W H B^2}{2} = \frac{H^3}{6} \times \text{tang.}^2 \angle BDG \times W,$$

$$\text{and } B = H \text{ tang. } \angle BDG \frac{\sqrt{\frac{W}{3}}}{\sqrt{W}},$$

and for stability,

$$\frac{W H B^2}{2} = \frac{H^3}{3} \times \text{tang.}^2 \angle BDG \times W,$$

$$\text{and } B = H \text{ tang. } \angle BDG \frac{\sqrt{\frac{2W}{3}}}{\sqrt{W}}.$$

The figures in the columns of Table No. 1, are calculated from this last formula, and are

$$H \text{ tang. } \angle BDG \sqrt{\frac{2W}{3}},$$

so if divided by the square root of the weight of a cubic foot of the wall, they will give the thickness of the wall.

Table No. 2 gives double the moments of the pressure of the weight of different materials to form the embankment, calculated from the formula

$$\frac{H^3}{3} \times \text{tang.}^2 \angle BDG \times W,$$

and which, if made equal to either of the moments of the weight of different forms of retaining walls given, the dimensions of that form of retaining wall required can be readily ascertained.

Having now given the usual formulæ and Tables for easy calculation deduced from them, for calculating the dimensions of a retaining wall with an embankment level with its top, what is next required is a convenient and ready method of accurately calculating the pressure of a surcharged embankment. The author is not aware if the method of calculation and formulæ he gives here are new, but the Tables for general use have, he thinks, the merit of simplicity.

When the embankment slopes away upwards above the top of the wall, the calculation of its pressure is a little more complex, and no method of finding it has yet been given that is simple, or that can be easily used in practice. Moseley, Hann, and Rankine, in their works give equations very abstruse, and apparently of no practical application. Hann also takes into account the pressure of the slope of the embankment resting on the top of the wall, a refinement of the calculation practically altogether unnecessary, and which, by complicating the original equation, renders mistakes more likely to occur.

If A C be the natural slope of the embankment rising upwards above the top of the wall A B G H, B E a line parallel to it from the foot of the wall, B C bisecting the

$\angle$ A B E, then A B C is the portion of the embankment to be retained by the wall. Now when A B is vertical, the length of the slope to be retained, A C, will be equal to the height of the wall. If $\angle$ E B F = the angle of the slope of the embankment = ϕ, then

$$\angle ABC - \angle ACB = \frac{90° - \phi}{2},$$

and if H = height of the wall, then

$$BC = H \frac{\sin.\ (90° + \phi)}{\sin\left(\frac{90° - \phi}{2}\right)} = H\theta; AL = H\sqrt{1 - \frac{\theta^2}{4}},$$

and the weight of

$$BAC = \frac{WH^2}{2}\theta\sqrt{1 - \frac{\theta^2}{4}},$$

TABLE 1.—*Thickness of Vertical Retaining Walls, to sustain the Pressure of Earth, Sand, etc., level with its top. The Moment of the Wall is equal to twice that of the Earth, etc., to insure permanent stability.*

Height of wall.	Sand. $\angle = 30°$.		Shingle. $\angle = 40°$.		Dry earth. $\angle = 43°$.	Do., moist or natural. $\angle = 54°$.	Do., dense and compact. $\angle = 55°$.	Clay. $\angle = 16°$.	Clay. $\angle = 45°$.
	94 lbs.	120 lbs	119 lbs.	106 lbs.	94 lbs.	106 lbs.	125 lbs.	125 lbs.	125 lbs.
6	27.42	30.98	24.92	23.52	20.65	16.39	17.27	41.27	22.69
7	31.99	36.15	29.07	27.44	24.09	19.12	20.15	48.15	26.47
8	36.56	41.31	33.23	31.36	27.53	21.85	23.03	55.03	30.25
9	41.13	46.47	37.38	35.28	30.98	24.58	25.90	61.91	34.03
10	45.70	51.64	41.53	39.20	34.42	27.31	28.78	68.79	37.81
11	50.27	56.80	45.69	43.12	37.86	30.04	31.66	75.67	41.59
12	54.84	61.97	49.84	47.04	41.30	32.78	34.54	82.55	45.38
13	59.42	67.13	53.99	50.96	44.74	35.51	37.42	89.43	49.16
14	63.99	72.29	58.15	54.88	48.19	38.24	40.29	96 31	52.94
15	68.56	77.46	62.30	58.80	51.63	40.97	43.17	103.18	56.72
16	73.13	82.62	66.45	62.72	55.07	43.70	46.05	110.06	60.50
17	77.70	87.79	70.61	66.64	58.51	46.43	48.93	116.94	64.28
18	82.27	92.95	74.76	70.56	61.95	49.16	51.81	123.82	68.06
19	86.84	98.11	78.91	74.48	65.40	51.89	54.69	130.70	71.84
20	91.41	103.28	83.07	78.40	68.84	54.63	57.56	137.58	75.62
21	95.98	108.44	87.22	82.32	72.28	57.36	60.44	144.46	79.40
22	100.55	113.61	91.38	86.24	75.72	60.09	63.32	151.34	83.18
23	105.12	118.77	95.53	90.16	79.17	62.82	66.19	158.22	86.96
24	109.69	123.94	99.68	94.08	82.61	65.56	69.07	165.10	90.74
25	114.26	129.10	103.84	98.00	86.05	68.29	71.95	171.97	94.52
26	118.83	134.26	107.99	101.92	89.49	71.02	74.83	178.85	98.31
27	123.40	139.43	112.14	105.84	92.93	73.75	77.71	185.73	102.09
28	127.97	144.59	116.30	109.76	96.38	76.48	80.58	192.61	105.87
29	132.54	149 76	120.45	113.68	99.82	79.21	83.46	199.49	109.65
30	137.11	154.92	124.60	117.60	103.26	81.94	86.34	206.37	113.43

W being the weight of a cubic foot of the embankment. Pressure of the weight of

$$BAC = \frac{WH^2}{2}\theta\sqrt{1 - \frac{\theta^2}{4}} \times \text{tang.}\ \frac{90° - \phi}{2},$$

moment of pressure of weight of

$$BAC = \frac{WH^2}{2}\theta\sqrt{1 - \frac{\theta^2}{4}} \times \text{tang.}\ \frac{90° - \phi}{2} \times \frac{H}{3} =$$

$$\frac{WH^3}{6}\theta\sqrt{1 - \frac{\theta^2}{4}} \times \text{tang.}\ \frac{90° - \phi}{2},$$

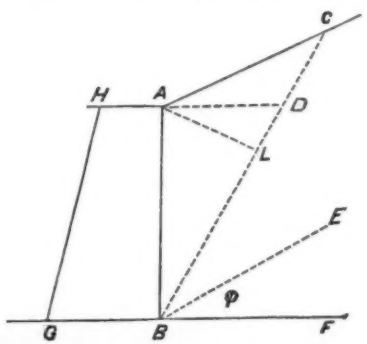
double this moment for stability

$$= \frac{WH^3}{3}\theta\sqrt{1 - \frac{\theta^2}{4}} \times \text{tang.}\ \frac{90° - \phi}{2}.$$

Table No. 3 gives the value of

$$\left(\theta\sqrt{1 - \frac{\theta^2}{4}} \times \text{tang.}\ \frac{90° - \phi}{2}\right) = c,$$

for every deg. of inclination of the slope of the embankment from 15 deg. to 40 deg., so that by multiplying $\frac{WH^3}{3}$ by this value, double the moment of the pressure of the embankment will be given, and Table No. 5 gives double the moments of different kinds of material accordingly.



In the case of a vertical wall, the moment of its weight $= \frac{W H B^2}{2}$, W being the weight of a cubic foot of the wall. Then for equilibrium,

$$\frac{W H B^2}{2} = \frac{c W H^3}{6}, \text{ and } B = .5773 H \frac{\sqrt{c W}}{\sqrt{W}},$$

and for stability,

$$\frac{W H B^2}{2} = \frac{c W H^3}{3}, \text{ and } B = .81649 H \frac{\sqrt{c W}}{\sqrt{W}}.$$

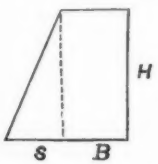
Table No. 4 is calculated from the formula $.81649 H \sqrt{c W}$, so that the figures in that Table, divided by the square root of the weight of a cubic foot of the wall, will give the thickness of the wall required for stability.

Table No. 5 gives double the moments of the pressure of the weight of different materials to form a surcharged embankment, with a retaining wall up to 30 ft. in height, and which if made equal to either of the moments of the weight of different forms of retaining walls given afterwards, the dimensions required for that form of wall can be at once found.

The moment of a wall of this section is

$$\frac{W H}{2}\left((B + S)^2 - \frac{S^2}{3}\right),$$

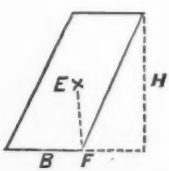
where B is the vertical portion of the wall,



and S is the slope. If $S = \frac{1}{4}$, or 3″ to a ft., its moment

$$= \frac{W H}{2}\left(\left(B \times \frac{H}{4}\right)^2 - \frac{H^2}{48}\right).$$

The moment of a battering wall of equal thickness



$$= \frac{W H B}{2}(B + S H),$$

where B = thickness of wall, and S H = the batter of the slope on the face. If

$$S = \frac{1}{4}, \text{ its moment} = \frac{W H B}{2}\left(B + \frac{H}{4}\right),$$

and if E F, the perpendicular from its centre of gravity, falls on its inside corner, its moment = W H B², and the wall then will have the greatest amount of resisting power with security, and also with a minimum amount of material in it. In that case, if M = moment of earth, W = weight of a cubic foot of the wall; for stability,

$$S = \sqrt{\frac{2 M}{W H^3}}, \text{ S H being} = B.$$

To exemplify this, let H = 20 feet, $S = \frac{1}{4}$, W = sand of 120 lbs. to the cubic foot in a surcharged embankment, W = brick of 120 lbs. to the cubic foot in the wall. Then by Table No. 5, the double moment of that kind of sand = 160,000. Then for the first section of wall,

$$\frac{120 \times 20}{2}\left(\left(B + \frac{20}{4}\right)^2 - \frac{20^2}{48}\right) = 160{,}000, \text{ and}$$

B = 6.9. In this case, weight of wall

$$= 120\left((20 \times 6.9) + \left(\frac{5 \times 20}{2}\right)\right) = 22{,}560.$$

For second section of wall,

$$\frac{B \times 20 \times 120}{2}\left(B + \frac{20}{4}\right) = 160{,}000,$$

and B = 9.31, weight of wall = 9.31 × 20 × 120 = 22344. For second section of wall, and a perpendicular from its centre of gravity to fall on its inside corner, 120 × 20 × B² = 160,000, and B = 8.16, weight of wall = 8.16 × 120 × 20 = 19593 only, showing a considerable saving of material with this wall.

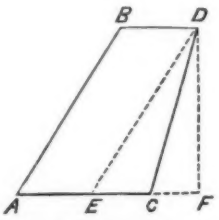
At the same time, though this wall has the greatest amount of resisting power with the smallest amount of material in it, yet perhaps it may be a question if it would not be advisable to make walls of great height thicker from their base upwards to one-third of their height, which is the centre of pressure.

If we now consider a wall of this form of cross-section, the outside slope of which is S to 1, and the inside slope next to the embankment S′ to 1, we find that its weight is

$$W H B + \frac{W H^2}{2}(S - S'),$$

and the moment of its weight

$$= \frac{W H}{2} \left(H (S - S') \left(\frac{2 S H - S' H}{3} + B \right) + B (S H + B) \right),$$



or if we call it C E and C F, where C E is the difference between the slopes of the front and back of the wall, D E being drawn parallel to the face A B, and C F is the batter of the back of the wall, then its weight is

$$= W H \left(B + \frac{E C}{2} \right),$$

and the moment of its weight

$$= W H \left(B \left(\frac{E F + B}{2} \right) + E C \left(\frac{E C}{3} + \frac{C F}{6} + \frac{B}{2} \right) \right).$$

Then, if the height of the wall be 20 ft., and its weight be 120 lbs. per cubic foot, as before, its outside slope $\frac{1}{4}$ to 1, and its inside slope next to the embankment $\frac{1}{8}$ to 1, then C F $= 2\frac{1}{2}$ ft., E C $= 2\frac{1}{2}$ ft., and its moment

$$= 120 \times 20 \left(B \left(\frac{5 + B}{2} \right) + 2\tfrac{1}{2} \left(\frac{2\frac{1}{2}}{3} + \frac{2\frac{1}{2}}{6} + \frac{B}{2} \right) \right)$$

$= 160{,}000$, the double moment of the embankment.

From this equation we find B $= 8.088$, and therefore the weight of that wall

$$= 120 \times 20 \left(8.088 + \frac{2.5}{2} \right) = 22411,$$

and which is, what might have been expected from the form of its cross-section, being between that of the first form of wall before mentioned, whose weight was 22560, and that of the second form, whose weight was 22344, less than the one and more than the other.

The form of cross-section of wall, having its front and back parallel, with the perpendicular from its centre of gravity falling on its inside corner, having been proved to be the most economical in material, it may be asked, why should not this principle be carried further, and walls generally be built thicker at the top than at the bottom, so as to have their centre of gravity higher up? This, by increasing the distance of a per-

TABLE 2.—*Double Moments of the Pressure of the Weight of Embankments of Earth, Sand, etc., level with the top of Wall.*

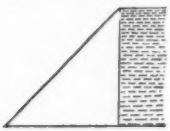
	Sand.		Shingle.		Dry earth.	Do., moist or natural.	Do., dense and compact.	Clay.		Water.
$\frac{c W H^3}{3}$	$= 10.4\ H^3$	$13.5\ H^3$	$8.62522\ H^3$	$7.6829\ H^3$	$5.92394\ H^3$	$3.73024\ H^3$	$4.14222\ H^3$	$23.66012 H^3$	$7.14887\ H^3$	$20.83\ H^3$
6	2256	2880	1863	1659	1280	806	895	5110	1544	4500
7	3582	4573	2958	2635	2032	1279	1421	8115	2452	7146
8	5347	6827	4416	3934	3033	1910	2121	12114	3660	10666
9	7614	9720	6287	5601	4318	2719	3020	17248	5211	15187
10	10444	13333	8625	7683	5924	3730	4142	23660	7149	20833
11	13901	17747	11480	10226	7885	4965	5513	31492	9515	27729
12	18048	23040	14904	13276	10236	6446	7158	40885	12353	36000
13	22946	29293	18949	16879	13015	8195	9100	51981	15706	45771
14	28659	36587	23667	21081	16255	10236	11366	64923	19616	57166
15	35250	45000	29110	25929	19993	12590	13980	79853	24127	70312
16	42780	54613	35329	31468	24264	15279	16966	96912	29282	85333
17	51313	65507	42376	37745	29104	18327	20251	116242	35122	102354
18	60912	77766	50302	44805	34548	21755	24157	137986	41692	121500
19	71638	91453	59160	52606	40632	25586	28411	162285	49034	142896
20	83555	106666	69002	61461	47391	29842	33138	189281	57191	166666
21	96726	123480	79878	71149	54862	34546	38361	219116	66206	192937
22	111212	141973	91841	81805	63078	39720	44106	251933	76121	221833
23	127077	162227	104943	93475	72077	45386	50398	287873	86980	253479
24	144384	184320	119235	106206	81892	51567	57262	327077	98826	288000
25	163194	208333	134769	121042	92561	58285	64722	369689	111701	325521
26	183571	234346	151597	135035	104119	65563	72804	415850	125650	366166
27	205578	262440	169770	151222	116601	73422	81531	465702	140711	410062
28	229276	292693	189341	168655	130042	81886	90930	519387	156932	457333
29	254729	325186	210360	187378	144479	90977	101025	577046	174354	508104
30	282000	360000	232881	207438	159946	100716	111840	638823	193019	562499

pendicular from it to the outside edge of the wall at its foot, would much increase its resisting power to the overturning force of the bank. It no doubt could be done, and where the wall is of great thickness it may be safe to do so, but as there is a fear, however, of too much reducing the thickness of the wall at one-third of its height, where is the centre of pressure, perhaps it may be advisable to make the form of equal thickness throughout, the limit of our endeavor to economize material with these forms of wall.

The moment of this form of wall, with its vertical side against the embankment, is

$$\frac{W\,H\,B^2}{3},$$

and if it be required to support water, whose



double moment is $20.83\,H^3$, we find from the equation

$$\frac{W\,H\,B^2}{3} = 20.83\,H^3,\ B = \frac{7.9\,H}{\sqrt{W}},$$

W being the weight of a cubic foot of the wall.

When the sloping side of the wall is next to the water, the pressure of the water on it assists the resisting power of the wall. Its moment is

$$\frac{W\,H\,B^2}{6},$$

and the pressure of the water on the slope

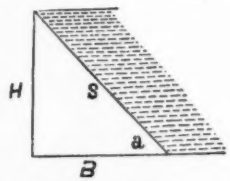
$$S = 62.5\,S \times \frac{H}{2} = 31.25\,S\,H.$$

Thus, when resolved into the horizontal and vertical forces, the former is

$$31.25\,S\,H \times \sin.\ \angle\ a = 31.25\,S\,H \times \frac{H}{S} = 31.25\,H^2,$$

and the latter is

$$31.25\,S\,H \times \cos.\ a = 31.25\,S\,H \times \frac{B}{S} = 31.25\,HB.$$



The moment of the former force

$$= 31.25\,H^2 \times \frac{H}{3} = 10.41\dot{6}\,H^3,$$

and which tends to overturn the wall; and the moment of the latter force

$$= 31.25\,H\,B \times \frac{2\,B}{3} = 20.8\dot{3}\,H\,B^2,$$

and which tends to assist the wall. The total moment of the wall for stability must therefore $= 2$ (moment horizontal force $-$ moment vertical force)

$$= 2\,(10.41\dot{6}\,H^3 - 20.8\dot{3}\,H\,B^2) =$$
$$20.8\dot{3}\,H\,(H^2 - 2\,B^2).$$

Then

$$\frac{W\,H\,B^2}{6} = 20.8\dot{3}\,H\,(H^2 - 2\,B^2),$$

and

$$B = \frac{11.18\,H}{\sqrt{W + 250}}.$$

If we take $H = 20$ feet, and $W = 120$ lbs. per cubic foot, then in the first case,

$$B = \frac{7.9 \times 20}{\sqrt{120}} = 14.42,$$

and the weight of the wall

$$= \frac{120 \times 20 \times 14.42}{2} = 17304;$$

and in the second case

$$B = \frac{11.18 \times 20}{\sqrt{120 + 250}} 11.62,$$

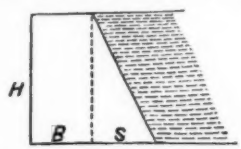
and the weight of the wall

$$= \frac{120 \times 20 \times 11.62}{2} = 13949.$$

The moment of a wall of this section is

$$\frac{W\,H}{2}\left((B + S)^2 - \frac{S^2}{3}\right),$$

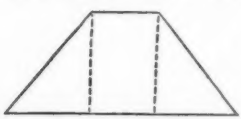
as before mentioned, when the water presses



against the vertical side, but if it is on the slope, the moment is

$$\frac{W\,H}{2}\left(B\,(B + S) + \frac{S^2}{3}\right).$$

If we have an embankment of this form of

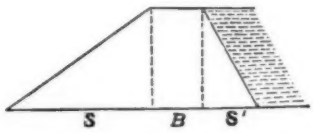


cross-section, where the slopes are the same on both sides, its moment is

$$W H \left(B \left(\frac{B + 3 S}{2} \right) + S^2 \right).$$

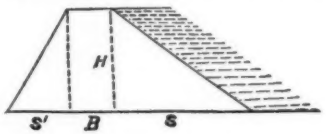
If the steeper slope is on the inside of the embankment, its moment is

$$W H \left(B \left(S + \frac{B + S'}{2} \right) + \left(S + \frac{S'}{2} \right) \left(\frac{S + S'}{3} \right) \right)$$



If the steeper slope is on the outside of the embankment, its moment is

$$W H \left(B \left(S' + \frac{B + S}{2} \right) + \left(S' + \frac{S}{2} \right) \left(\frac{S' + S}{3} \right) \right).$$



If in these last five equations $W = 120$ lbs. to the cubic foot, $H = 20$ feet, $S = 20$ feet, $S' = 10$ feet, and $B = 10$ feet, then the moment of the first section

$$= \frac{120 \times 20}{2} \left((10 + 20)^2 - \frac{20^2}{3} \right) = 920{,}000;$$

of the second section

$$= \frac{120 \times 20}{2} \left(10 \, (10 + 20) + \frac{20^2}{3} \right) = 520{,}000;$$

of the third section

$$= 120 \times 20 \left(10 \left(\frac{10 + 3 \times 20}{2} \right) + 20^2 \right)$$
$$= 1{,}800{,}000;$$

of the fourth section

$$= 120 \times 20 \left(10 \left(20 + \frac{10 + 10}{2} \right) + \left(20 + \frac{10}{2} \right) \left(\frac{20 + 10}{3} \right) \right) = 1{,}320{,}000;$$

of the fifth section

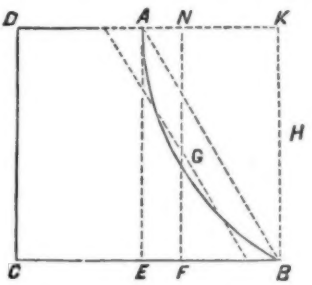
$$= 120 \times 20 \left(10 \left(10 + \frac{10 + 20}{2} \right) + \left(10 + \frac{20}{2} \right) \left(\frac{10 + 20}{3} \right) \right) = 1{,}080{,}000.$$

In these equations the moments of the walls are to be made equal to twice the difference of the moments of the horizontal and vertical forces of the water, as before, when the sloping side is next to the water. If the wall is to be built with a curved batter instead of a slope, to facilitate the calculation of its moment we may assume the curve to be of a parabolic form, and from which, in the curves generally used for that purpose, it will not sensibly differ. The calculations of the moments of a few forms of wall with curved batter are given, to show how they have been arrived at.

To find the moment of a retaining wall with curved batter generally, let A B E be of the parabolic form, then the area of

$$A B E = \frac{H}{3} \times B E.$$

Now the centre of gravity of A B E will be found sufficiently correct for all practical purposes if it is taken to be in the perpendicular line G F, which will bisect A B E. Now



$$A E F G = A E F N - A G N =$$
$$H \times E F - \frac{2}{3} G N \times E F = \frac{A B E}{2} = \frac{H}{6} \times B E,$$
$$A K = B E : B K^2 - H^2 : : A N = E F : G N^2,$$
$$G N = H \sqrt{\frac{E F}{B E}}$$
$$H \times E F - \frac{2}{3} H \sqrt{\frac{E F}{B E}} \times E F = \frac{H}{6} B E,$$
$$\frac{2}{3} \sqrt{\frac{E F}{B E}} = 1 - \frac{B E}{6 E F},$$
$$\frac{E F}{B E} = \frac{9}{4} - \frac{3 B E}{4 E F} + \frac{B E^2}{16 E F^2},$$
$$B E^3 - 12 B E^2 \times E F + 36 B E \times E F^2 - 16 E F^3 = 0,$$
$$(B E - 4 E F)(B E^2 - 8 B E \times E F + 4 E F^2) = 0,$$
$$B E - 4 E F = 0, \; B F = \frac{3 B E}{4}.$$

Moment of

$$A B E = \frac{H}{3} B E \times \frac{3 B E}{4} = H \frac{B E^2}{4};$$

moment of

$$A E C D = (H \times C E) \left(B E + \frac{C E}{2} \right);$$

moment of

$$ABCD = H\left(\frac{CE^2}{2} + CE \times BE + \frac{BE^2}{4}\right)$$

$$= \frac{H}{2}\left((CE + BE)^2 - \frac{BE^2}{2}\right).$$

If we take a triangle of equal area with A G B E, and similar to a triangle A B E, we shall find that its base will

$$= BE\sqrt{\frac{2}{3}} = .8165\,BE,$$

and therefore the distance of a perpendicular from its centre of gravity to

$$E = \frac{.8165\,BE}{3} = .2722\,BE,$$

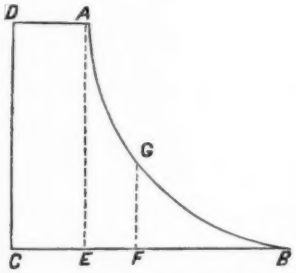
and therefore, $BE - .2722\,BE = .7278\,BE$ from B, or nearly the same as before. Let $CE = 6$, and other values as before, then

$$120\frac{20}{2}\left((6 + BE)^2 - \frac{BE^2}{2}\right) =$$

$$160{,}000,\ BE = 6.403,$$

and weight of wall

$$= 120\left(20 \times 6 + \frac{1}{3}\,20 \times 6.4\right) = 19523.$$



To find the moment of A B C D when A B E = A E C D. Then

$BE = 3\,CE$, area of $ABE = H \times \frac{BE}{3} = H \times CE$.

Moment of

$$ABCD = (H \times CE)\left(BE + \frac{CE}{2}\right) +$$

$$\left(H \times \frac{BE}{3}\right)\left(\frac{3\,BE}{4}\right) - (H \times CE)$$

$$\left(3\,CE + \frac{CE}{2}\right) + (H \times CE)\,\frac{3}{4}3\,CE = H\frac{7}{2}\,CE^2$$

$$+ H\frac{9}{4}\,CE^2 = H\frac{23}{4}\,CE^2 = H\frac{23}{64}\,BC^2.$$

Then

$$120 \times 20\frac{23}{64}\,BC^2 = 160{,}000,$$

$$BC = 13.62,\ CE = 3.4,\ BE = 10.21,$$

and weight of wall

$$= 120\left(20 \times 3.4 + 20\frac{10.21}{3}\right) = 16344.$$

When both the front and back of the wall are curved and parallel. When E F passes through the centre of gravity, to find E A. Area of

$$EABF = H \times EA + \frac{H}{3}(BF - EA) =$$

$$\frac{2H}{3}EA + \frac{H}{3}BF,$$

area of

$$EFCD = H \times CF + \frac{2H}{3}(ED - CF)$$

$$= \frac{H}{3}CF + \frac{2H}{3}ED,$$

then, when E F bisects A B C D,

$$\frac{2H}{3}EA + \frac{H}{3}BF = \frac{H}{3}CF + \frac{2H}{3}ED,$$

$$BF = CF + 2(ED - EA).$$

For stability,

$$BF = \frac{3\,BC}{4} = \frac{3\,AD}{4},$$

$$CF = \frac{BC}{4} = \frac{AD}{4},$$

$$\frac{3\,AD}{4} = \frac{AD}{4} + 2(ED - EA),$$

$$AD = 4\,ED - 4\,EA,$$

and as

$$4\,AD = 4\,ED + 4\,EA,$$

$$3\,AD = 8\,EA,\ EA = \frac{3}{8}AD.$$

To find E A when the perpendicular which bisects A B C D passing through its centre of gravity falls on its inside corner. Area of

$$ECD = \frac{2}{3}H \times ED = \frac{2}{3}H(AD - EA).$$

Area of

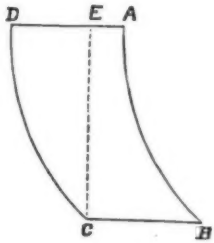
$$ABCE = H \times EA + \frac{H}{3}(BC - EA),$$

$$\frac{2H}{3}(AD - EA) = H \times EA + \frac{H}{3}(BC - EA),$$

$$= \frac{2H}{3}EA + \frac{H}{3}BC,$$

$$\frac{4H}{3}EA = \frac{2H}{3}AD - \frac{H}{3}BC = \frac{H}{3}BC,$$

$$EA = \frac{BC}{4}.$$



To find the moment of A B C D when the curves of the front and back of the wall are of different radii. Area of

$$EFCD = H \times CF + \frac{2H}{3}(DE - CF)$$

$$= \frac{H}{3}CF + \frac{2H}{3}DE,$$

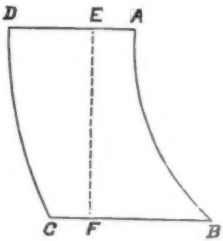
area of

$$EABF = H \times EA + \frac{H}{3}(BF - EA)$$

$$= \frac{2H}{3}EA + \frac{H}{3}BF,$$

area of

$$ABCD = \frac{H}{3}CF + \frac{2H}{3}DE + \frac{2H}{3}EA + \frac{H}{3}BF = \frac{H}{3}(BC + 2DA);$$



moment of A B C D for stability

$$= \frac{3BC}{4} \times \frac{H}{3}(BC + 2DA)$$

$$= \frac{H \times BC}{4}(BC + 2DA).$$

TABLE 3.—*For Surcharged Embankments.*

∠ of slope = ϕ.	∠ A B C = $\frac{90° - \phi}{2}$	Tang. of $\frac{90° - \phi}{2}$	$\theta = \frac{\sin.(90° + \phi)}{\sin.\left(\frac{90° - \phi}{2}\right)}$	$\theta\sqrt{1 - \frac{\theta^2}{4}}$	Tang. of $\frac{90° - \phi}{2}$ $\left(\theta\sqrt{1 - \frac{\theta^2}{4}}\right)$
4 to 1 = 14° 12′	37° 54′	.77847	1.5782	0.96944	0.75469
15 0	37 30	.76732	1.5867	0.96592	0.74118
16 0	37 0	.75355	1.5972	0.96126	0.72436
17 0	36 30	.73996	1.6077	0.95630	0.70762
18 0	36 0	.72654	1.6180	0.95105	0.69098
3 to 1 = 18 25	35 47½	.72100	1.6223	0.94878	0.68407
19 0	35 30	.71329	1.6282	0.94551	0.67443
20 0	35 0	.70020	1.6383	0.93969	0.65798
21 0	34 30	.68728	1.6483	0.93358	0.64163
22 0	34 0	.67450	1.6581	0.92718	0.62539
23 0	33 30	.66188	1.6678	0.92050	0.60926
24 0	33 0	.64940	1.6773	0.91354	0.59326
25 0	32 30	.63707	1.6868	0.90630	0.57738
26 0	32 0	.62486	1.6961	0.89879	0.56162
2 to 1 = 26 35	31 42½	.61781	1.7014	0.89428	0.55250
27 0	31 30	.61280	1.7053	0.89100	0.54601
28 0	31 0	.60086	1.7143	0.88294	0.53052
29 0	30 30	.58904	1.7232	0.87461	0.51519
1¾ to 1 = 29 44	30 8	.58045	1.7297	0.86834	0.50403
30 0	30 0	.57735	1.7320	0.86602	0.50000
31 0	29 30	.56577	1.7407	0.85716	0.48496
32 0	29 0	.55430	1.7492	0.84804	0.47003
33 0	28 30	.54295	1.7576	0.83867	0.45536
1½ to 1 = 33 42	28 9	.53507	1.7634	0.83195	0.44515
34 0	28 0	.53170	1.7659	0.82903	0.44080
35 0	27 30	.52056	1.7740	0.81915	0.42642
36 0	27 0	.50952	1.7820	0.80901	0.41221
37 0	26 30	.49858	1.7899	0.79863	0.39818
38 0	26 0	.48773	1.7976	0.78801	0.38433
1¼ to 1 = 38 40	25 40	.48055	1.8026	0.78079	0.37521
39 0	25 30	.47697	1.80517	0.77714	0.37067
40 0	25 0	.46630	1.81261	0.76604	0.35721

As

$$\frac{H}{3} C F + \frac{2H}{3} D E = \frac{2H}{3} E A + \frac{H}{3} B F,$$

$$C F + 2 D E = 2 E A + B F,$$

adding 2 E A to both sides,

$$C F + 2 D A = 4 E A + B F,$$

$$E A = \frac{2 D A + C F - B F}{4}$$

generally, and for stability,

$$E A = \frac{D A}{2} + \frac{\frac{B C}{4}}{4} - \frac{\frac{3 B C}{4}}{4} = \frac{D A}{2} - \frac{B C}{8}.$$

If D A is to be $\frac{3}{4}$ B C, then the moment

$$\frac{H \times B C}{4} (B C + 2 D A)$$

will be

$$\frac{H \times B C}{4} \left(B C + \frac{3}{2} B C \right) = H \frac{5 B C^2}{8}.$$

Then, with values as before,

$$120 \times 20 \frac{5 B C^2}{8} = 160{,}000, \quad B C = 10.32,$$

$$D A = \frac{3}{4} 10.32 = 7.74,$$

weight of wall

$$= 120 \times \frac{20}{3} (10.32 + 2 \times 7.74) = 20640.$$

If D A is to be $\frac{2}{3}$ B C, then the moment

$$\frac{H \times B C}{4} (B C + 2 D A)$$

will be

$$\frac{H \times B C}{4} \left(B C + \frac{4}{3} B C \right) = H \frac{7 B C^2}{12}.$$

Then, with values as before,

$$120 \times 20 \frac{7 B C^2}{12} = 160{,}000, \quad B C = 10.69,$$

$$D A = \frac{2}{3} 10.69 = 7.13,$$

weight of wall

$$= 120 \times \frac{20}{3} (10\ 69 + 2 \times 7.13) = 19960.$$

If D A is to be $\frac{1}{2}$ B C, then the moment

$$\frac{H \times B C}{4} (B C + 2 D A)$$

will be

$$\frac{H \times B C}{4} (B C + B C) = H \frac{B C^2}{2}.$$

Then, with values as before,

$$120 \times 20 \frac{B C^2}{2} = 160{,}000, \quad B C = 11.54,$$

$$D A = \frac{1}{2} 11.54 = 5.77,$$

weight of wall

$$= 120 \times \frac{20}{3} (11.54 + 2 \times 5.77) = 18464.$$

If D A is to be $\frac{1}{4}$ B C, then the moment

$$\frac{H \times B C}{4} (B C + 2 D A)$$

will be

$$\frac{H \times B C}{4} \left(B C + \frac{1}{2} B C \right) = H \frac{3 B C^2}{8}.$$

Then, with values as before,

$$120 \times 20 \frac{3 B C^2}{8} = 160{,}000, \quad B C = 13.\dot{3},$$

$$D A = \frac{1}{4} 13\ \dot{3} = 3.\dot{3},$$

weight of wall

$$= 120 \times \frac{20}{3} (13.\dot{3} + 2 \times 3.\dot{3}) = 16000.$$

If a wall of this section is required, its moment is

$$H \times \frac{B C^2}{4},$$

and if it supports water level with the top,

$$120 \times 20 \frac{B C^2}{4} = 166{,}666, \quad B C = 16.\dot{6};$$

and weight of wall

$$= 120 \times 20 \times \frac{16.6}{3} = 13333.$$

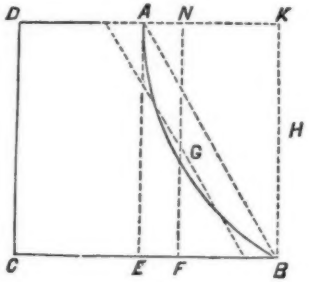
Now as 17304 was required for the triangular form of wall with the same values, there is shown to be a great saving of material with the form of wall with curved batter.

As the form of wall with a curved batter of the semi-cubical parabolic section, has been proved by several writers to be everywhere of equal strength, the calculations for finding the dimensions of retaining walls with a batter of that curve are also given, as they may be found useful in some

cases. Let A G B in this figure be a curve of that form, with G F passing through its centre of gravity. Then

$$AK^2 = BE^2 : BK^3 = H^3 :: AH^2 = EF^2 : GN^3,$$

$$GN = H\sqrt[3]{\frac{EF^2}{BE^2}},$$



area of $$ABE = \frac{2H}{5} \times BE,$$

area of $$AGN = \frac{3AN}{5} \times GH,$$

area of $$AEFG = H \times EF - \frac{3}{5} AN \times GN,$$

$$H \times EF - \frac{3}{5} AN \times NG = \frac{H}{5} \times BE,$$

$$H \times EF - \frac{3}{5} EF \times H\sqrt[3]{\frac{EF^2}{BE^2}} = \frac{H}{5} \times BE,$$

$$EF - \frac{3}{5} EF\sqrt[3]{\frac{EF^2}{BE^2}} = \frac{BE}{5},$$

$$\frac{3}{5} EF\sqrt[3]{\frac{EF^2}{BE^2}} = EF - \frac{BE}{5},$$

$$EF\sqrt[3]{\frac{EF^2}{BE^2}} = \frac{5EF}{3} - \frac{BE}{3},$$

$$\sqrt[3]{\frac{EF^2}{BE^2}} = \frac{5}{3} - \frac{BE}{3EF} = \frac{5 - \frac{BE}{EF}}{3},$$

$$\frac{EF^2}{BE^2} = \frac{\left(5 - \frac{BE}{EF}\right)^3}{27}, \quad \frac{\left(5 - \frac{BE}{EF}\right)^3}{\frac{EF^2}{BE^2}} = 27,$$

$$\frac{BE^2}{EF^2}\left(5 - \frac{BE}{EF}\right)^2 = 27, \quad \frac{BE}{EF} = 3.759,$$

$$BE = 3.759\,EF = 3.759\,(BE - BF),$$

$$3.759\,BF = 3.759\,BE - BE,$$

$$BF = \frac{2.759\,BE}{3.759} = .734\,BE.$$

Moment of

$$ABE = \frac{2H}{5} BE \times .734\,BE = .2936\,BE^2 \times H;$$

moment of

$$AECD = (H \times CE)\left(BE + \frac{CE}{2}\right);$$

moment of

$$ABCD = H\left(\frac{CE^2}{2} + CE \times BE + .2936BE^2\right)$$

$$= \frac{H}{2}\left((CE + BE)^2 - .4128\,BE^2\right).$$

TABLE 4.—*Thickness of Vertical Retaining Walls to sustain the Pressure of a Surcharged Embankment of Earth, Sand, etc. The moment of the Wall is equal to twice that of the Earth, etc., to insure permanent stability.*

Height of wall.	Sand. $\angle = 30°$. $c = 0.500$		Shingle. $\angle = 40°$. $c = 0.35721$		Dry earth. $\angle = 45°$. $c = .318001$	Do., moist or natural. $\angle = 54°$. $c = .190683$	Do., dense and compact. $\angle = 55°$. $c = .1808438$	Clay. $\angle = 16°$.	Clay. $\angle = 45°$.
	94 lbs.	120 lbs.	119 lbs.	106 lbs.	94 lbs.	106 lbs.	125 lbs.	125 lbs.	125 lbs.
6	33.58	37.94	31.94	30.14	26.78	22.04	23.29	46.61	29.64
7	39.18	44.27	37.26	35.17	31.24	25.71	27.17	54.38	34.58
8	44.78	50.59	42.58	40.19	35.71	29.39	31.05	62.15	39.52
9	50.37	56.92	47.91	45 21	40.17	33.06	34.93	69.92	44.46
10	55.97	63.24	53.23	50.24	44.64	36.73	38.82	77.69	49.40
11	61 57	69.57	58.55	55.26	49.10	40.41	42.70	85.46	54.34
12	67.17	75.89	63.88	60.29	53.56	44.08	46.58	93.23	59.28
13	72.76	82.21	69.20	65.31	58.03	47.75	50.46	101.00	64.22
14	78.36	88.54	74.52	70.33	62.49	51.43	54.34	108.77	69.16
15	83.96	94.86	79.85	75.36	66.96	55.10	58.23	116.54	74.10
16	89.56	101.19	85.17	80.38	71.42	58.78	62.11	124.31	79.04
17	95.16	107.51	90.49	85.41	75.89	62.45	65.99	132.08	83.98
18	100.75	113.84	95.82	90.43	80.35	66.12	69.87	139.85	88.92
19	106.35	120.16	101.14	95.46	84.81	69.80	73.75	147.62	93.86
20	111.95	126.49	106.46	100.48	89.28	73 47	77.64	155.39	98.80
21	117.55	132.81	111.79	105 50	93.74	77.14	81.52	163.16	103.74
22	123.14	139.14	117.11	110.53	98.21	80.82	85.40	170.93	108.68
23	128.74	145.46	122.43	115.55	102.67	84.49	89.28	178.70	113.62
24	134 34	151.78	127.76	120.58	107.13	88.16	93.16	186.47	118.56
25	139.94	158 11	133.08	125 60	111.60	91.84	97.05	194.24	123.50
26	145.54	164.44	138.41	130.63	116.07	95.52	100.93	202.01	128.45
27	151.13	170.76	143.73	135.65	120.53	99.19	104.81	209.78	133.39
28	156.73	177.09	149.05	140.68	124.99	102 86	108.70	217.55	138.33
29	162.33	183.41	154.38	145.70	129.46	106.54	112.58	225.32	143.27
30	167.93	189.74	159.70	150.73	133.92	110.21	116.46	233.10	148.21

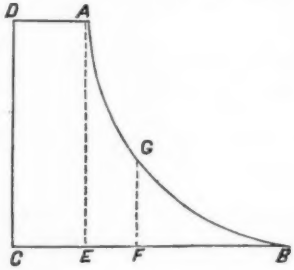
Let $CE = 6$, and other values as before, then

$$120\,\frac{20}{2}\,((6 + BE)^2 - .4128\,BE^2) = 160{,}000,$$

$BE = 6.22$, and weight of wall

$$= 120\left(20 \times 6 + \frac{2}{5}\,20 \times 6.22\right) = 20369.$$

To find the moment of $ABCD$ when $ABE = AECD$. Then $BE = \frac{5}{2}\,CE$, area of $ABE = H \times \frac{2}{5}\,BE = H \times CE$.



Moment of

$$ABCD = (H \times CE)\left(BE + \frac{CE}{2}\right) + \left(H \times \frac{2}{5}\,BE\right)(.734\,BE) = (H \times CE)\left(\frac{5}{2}\,CE + \frac{CE}{2}\right) + (H \times CE)\left(.734 \times \frac{5}{2}\,CE\right)$$

$$= (H \times CE)\,3\,CE + (H \times CE)\,1.835\,CE = 4.835\,H \times CE^2.$$

Then $120 \times 20 \times 4.835\,CE^2 = 160{,}000$, $CE = 3.71$, $BE = \frac{5}{2}\,3.71 = 9.28$, and weight of wall

$$= 120 \times 20\left(3.71 + \frac{2}{5}\,9.28\right) = 17808.$$

When both the front and back of the wall are curved and parallel. When EF passes through the centre of gravity, to find EA. Area of

$$EABF = H \times EA + \frac{2H}{5}(BF - EA) = \frac{3H}{5}\,EA + \frac{2H}{5}\,BF,$$

area of

$$EFCD = H \times CF + \frac{3H}{5}(ED - CF) = \frac{2H}{5}\,CF + \frac{3H}{5}\,ED,$$

then when EF bisects $ABCD$,

$$\frac{3H}{5}\,EA + \frac{2H}{5}\,BF = \frac{2H}{5}\,CF + \frac{3H}{5}\,ED,$$

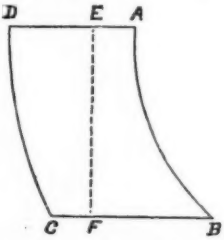
$$2BF = 2CF + 3ED - 3EA;$$

for stability,

$$BF = \frac{3BC}{4} = \frac{3AD}{4},\quad CF = \frac{AD}{4},$$

so

$$\frac{3AD}{2} = \frac{AD}{2} + 3ED - 3EA,$$



$AD = 3ED - 3EA$, and as $3AD = 3ED + EA$, subtracting,

$$2AD = 6EA,\quad EA = \frac{AD}{3}.$$

To find EA when the perpendicular which bisects $ABCD$ passing through its centre of gravity, falls on its inside corner. Area of

$$ECD = \frac{3H}{5}\,ED = \frac{3H}{5}\,(AD - EA),$$

area of

$$ABCE = H \times EA + \frac{2H}{5}\,(BC - EA),$$

$$\frac{3H}{5}\,(AD - EA) = H \times EA + \frac{2H}{5}\,(BC - EA) = \frac{3H}{5}\,EA + \frac{2H}{5}\,BC,$$

$$\frac{6H}{5}\,EA = \frac{3H}{5}\,AD - \frac{2H}{5}\,BC = \frac{H}{5}\,BC,$$

$$EA = \frac{BC}{6}.$$

To find the moment of $ABCD$ when the curves of the front and back of the wall are of different radii. Area of

$$EFCD = H \times CF + \frac{3H}{5}\,(DE - CF) = \frac{2H}{5}\,CF + \frac{3H}{5}\,DE,$$

area of

$$EABF = H \times EA + \frac{2H}{5}(BF - EA)$$

$$= \frac{3H}{5} EA + \frac{2H}{5} BF,$$

area of

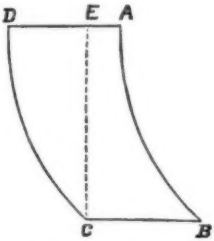
$$ABCD = \frac{2H}{5} CF + \frac{3H}{5} DE +$$

$$\frac{3H}{5} EA + \frac{2H}{5} BF = \frac{H}{5} (2BC + 3AD);$$

moment of A B C D for stability

$$= \frac{3BC}{4} \times \frac{H}{5} (2BC + 3AD)$$

$$= \frac{3H \times BC}{20} (2BC + 3AD).$$



As $\frac{2H}{5} CF + \frac{3H}{5} DE = \frac{3H}{5} EA + \frac{2H}{5} BE,$

$$2CF + 3DE = 3EA + 2BF,$$

adding 3 E A to both sides,

$$2CF + 3DA = 6EA + 2BF,$$

$$EA = \frac{3DA + 2CF - 2BF}{6}$$

generally, and for stability,

$$EA = \frac{3DA + \frac{BC}{2} - \frac{3BC}{2}}{6} = \frac{DA}{2} - \frac{BC}{6}.$$

If D A is to be $\frac{3}{4}$ B C, then the moment

$$\frac{3H \times BC}{20} (2BC + 3AD)$$

will be

$$\frac{3H \times BC}{20} \left(2BC + \frac{9}{4} BC\right) = \frac{H\,51\,BC^2}{80}.$$

Then, with values as before,

$$120 \times 20 \frac{51\,BC^2}{80} = 160{,}000,\ BC = 10.23,$$

$$DA = \frac{3}{4} 10.23 = 7.67,$$

weight of wall

$$= 120 \times \frac{20}{5} (2 \times 10.23 + 3 \times 7.67) = 20860.$$

If D A is to be $\frac{2}{3}$ B C, then the moment

$$\frac{3H \times BC}{20} (2BC + 3AD)$$

will be

$$\frac{3H \times BC}{20} (2BC + 2BC) = H \frac{3BC^2}{5}.$$

TABLE 5.—*Double Moments of the Pressure of the Weight of Surcharged Embankments of Earth, Sand, etc.*

	Sand.		Shingle.		Dry earth.	Do., moist or natural.	Do., dense and compact.	Clay.	
$\frac{c\,W\,H^3}{3}$	$= 15.6\,H^3$	$20\,H^3$	$14.16945\,H^3$	$12.62153\,H^3$	$9.96405\,H^3$	$6.748066\,H^3$	$7\,53526\,H^3$	$30.183\,H^3$	$12.20375\,H^3$
6	3384	4320	3061	2726	2152	1458	1627	6520	2636
7	5373	6860	4860	4329	3418	2315	2585	10353	4186
8	8021	10240	7255	6462	5102	3455	3858	15454	6248
9	11421	14580	10330	9201	7264	4919	5493	22004	8896
10	15666	20000	14169	12621	9964	6748	7535	30183	12204
11	20852	26620	18860	16709	13262	8982	10029	40174	16243
12	27072	34560	24485	21810	17218	11661	13021	52157	21088
13	34419	43940	31130	27729	21891	14825	16555	66313	26812
14	42989	54880	38881	34633	27341	18517	20677	82823	33487
15	52875	67500	47822	42598	33628	22775	25432	101869	41188
16	64170	81920	58038	51698	40813	27640	30864	123631	49986
17	76970	98260	69614	62010	48953	33153	37021	148291	59957
18	91368	116640	82636	73609	58110	39355	43946	176029	71172
19	107457	137180	97188	86571	68343	46285	51684	207027	83712
20	125333	160000	113355	100972	79712	53985	60282	241466	97630
21	145089	185220	131223	116888	92277	62494	69784	279528	113019
22	166818	212960	150876	134394	106097	72453	80235	321392	1 9945
23	190616	243340	172400	153566	121232	82104	91681	367241	148483
24	216576	276480	195878	174480	137743	93285	104167	417754	168704
25	244791	312500	221397	197211	155688	105438	117738	471615	190684
26	275357	351520	249042	221836	175128	118604	132439	530502	214493
27	308367	393660	278897	248429	196122	132822	148316	594098	240206
28	343914	439040	311048	277068	218731	148133	165414	662584	267897
29	382094	487780	345579	307826	243013	164578	183777	736141	297637
30	423000	540000	382575	340781	269029	182198	203452	814949	329501

Then, with values as before,

$$120 \times 20 \frac{3\,B\,C^2}{5} = 160{,}000,$$

$$B\,C = 10.54,\ D\,A = \frac{2}{3}\,10.54 = 7.03,$$

weight of wall

$$= 120 \times \frac{20}{5}\,(2 \times 10.54 + 3 \times 7.03) = 20238.$$

If D A is to be $\frac{1}{2}$ B C, then the moment

$$\frac{3\,H \times B\,C}{20}\,(2\,B\,C + 3\,A\,D)$$

will be

$$\frac{3\,H \times B\,C}{20}\left(2\,B\,C + \frac{3}{2}\,B\,C\right) = H\,\frac{21\,B\,C^2}{40}.$$

Then, with values as before,

$$120 \times 20 \frac{21\,B\,C^2}{40} = 160{,}000,$$

$$B\,C = 11.27,\ D\,A = \frac{1}{2}\,11.27 = 5.63,$$

weight of wall

$$= 120 \times \frac{20}{5}\,(2 \times 11.27 + 3 \times 5.63) = 18930.$$

If A D is to be $\frac{1}{3}$ B C, then the moment

$$\frac{3\,H \times B\,C}{20}\,(2\,B\,C + 3\,A\,D)$$

will be

$$\frac{3\,H \times B\,C}{20}\,(2\,B\,C + B\,C) = H\,\frac{9\,B\,C^2}{20}.$$

Then, with values as before,

$$120 \times 20 \frac{9\,B\,C^2}{20} = 160{,}000,$$

$$B\,C = 12.17,\ D\,A = \frac{1}{3}\,12.17 = 4.06,$$

weight of wall

$$= 120 \times \frac{20}{5}\,(2 \times 12.17 + 3 \times 4.06) = 17526.$$

If D A is to be $\frac{1}{4}$ B C, then the moment

$$\frac{3\,H \times B\,C}{20}\,(2\,B\,C + 3\,A\,D)$$

will be

$$\frac{3\,H \times B\,C}{20}\left(2\,B\,C + \frac{3}{4}\,B\,C\right) = H\,\frac{33\,B\,C^2}{80}.$$

Then, with values as before,

$$120 \times 20\,\frac{33\,B\,C^2}{80} = 160{,}000,$$

$$B\,C = 12.71,\ D\,A = \frac{1}{4}\,12.71 = 3.18,$$

weight of wall

$$= 120 \times \frac{20}{5}\,(2 \times 12.71 + 3 \times 3.18) = 16780.$$

If a wall of this section is required, its moment is .2936 B C^2 × H, and if it supports water level with the top,

$$120 \times 20 \times .2936\,B\,C^2 = 166{,}666,\ B\,C = 15.38,$$

and weight of wall

$$= 120 + 20 \times \frac{2 \times 15.38}{5} = 14764.$$

Having now given methods for finding the correct dimensions of the different forms of wall that are generally used in practice, the author does not wish to express any opinion on the merits of any particular form of wall, leaving it to the superior judgment of more experienced engineers to determine the section of wall they may consider most suitable in each case.

ON THE PAST AND PRESENT OF IRON SMELTING.

By Sr. JOHN VINCENT DAY.

From "Iron."

When we consider that in 1871 no less than 16,859,063 tons of iron ore were smelted in Great Britain alone, from which was produced 6,627,179 tons of pig iron, representing a money value at the works of £16,667,947 (Mineral Statistics, 1871), and which, for the corresponding period we have just passed through, must, by reason of an unprecedented demand for the material itself, and at unprecedented prices, be greatly increased; it will be readily admitted that our time may be profitably spent in considering the steps by which a manufacture, in former years carried on very much in the dark, has at length been reduced by conjoint labor to almost a scientific exacti-

tude. To say that iron smelting has yet been completely reduced to a science would be nothing other than pretence; nevertheless, with a given furnace, ore, fuel, flux, and blast, we can estimate within tolerably narrow limits the quality and quantity of the product. Yet there are numerous points in the true understanding of what takes place in the blast furnace which are still enshrined in the region of uncertainty.

Within the last forty years it may be said that iron smelting has begun by slow degrees to be scientifically understood. Mushet and Clark, in our own country, as well as several French and German chemists, have devoted their energies to the solution of various inquiries, wherewith the subject is entangled. But, since 1846, when the first furnace was built at the Walker Works by Mr. I. Lowthian Bell, for smelting the Cleveland iron stone, several other iron-making districts, with furnaces of colossal dimensions, have sprung up; and most important investigations have been carried out, the general results of which have led to improvements in practice, whereby the fuel required for smelting has been reduced by about 30 per cent., this being directly due to operating with a larger bulk and higher column of materials at a time; utilizing the waste gases for heating the blast, and generating steam for the blowing engines; and to a greatly elevated blast temperature.

No argument can be necessary to show why it is important, in dealing with the subject of this investigation, to attack it at the very foundation, for that must be self-evident to any one whom it may concern to understand it.

Any attempt at elucidating the course through which the modern gigantic operations of iron smelting have been reached involves at once the history of the manufacture of cast iron; and it is not too much to say that recent investigations into the subject, if they prove anything at all, prove among other things that the true history of cast iron still remains an unwritten chapter. However interesting, as well as useful, it might prove to probe the ultimate depths of that history, yet it is not proposed as a feature of this paper to attempt what must at present be so unfathomable a task.

By some researches, made a short time since, I was enabled to prove from a variety of consentaneous evidence, that malleable iron was well known and used at least as far back as 4,000 years ago, and almost certainly much earlier still. I was thereby, and of necessity, led to doubt whether the usually accepted assertion as to cast iron having been invented within the last three or four hundred years only, rested on an entirely stable and reliable basis. The sequel will show the results of the doubt so raised in my mind.

At first sight it appears out of keeping with an almost constant order, that the place and date, no less than the names of the first makers of cast iron, are not absolutely known.

When, however, we reflect upon that which we really do know concerning early methods of making iron and steel, weigh carefully the precise nature of the conditions involved under those methods, and seek out the results inevitably accruing through them as explained by the guiding light of modern chemistry, it would appear that the blast furnace, as a distinct apparatus, could scarcely at any time have consisted in a definite or sudden departure from an existing order of things; by saying which, I mean to explain, that in all probability there never was in the development of iron smelting, an immediate complete change made from the method of reducing ore at once to malleable metal (the direct method), to that of first making pig or sow metal (*i. e.*, the indirect method of the blast furnace as we practise it to day). On the contrary, the evidence which has been collected, goes to show that the blast furnace was ultimately reached—as a definite and distinct apparatus for reducing iron ore quickly, and producing an easily fusible compound of iron—by its accidental production, when reducing easily fusible ores in the air or in blast bloomeries, or other formerly used types of low furnaces, in which the product sought to be obtained was malleable iron or steel.

This probability, indeed, appears to rest on conclusive grounds; and the tendency of this evidence is farther to show that the blast furnace, as an apparatus, having as a distinct object the production of cast iron, was at last arrived at through very gradual accessions to the height of the ancient types of low furnaces.

Where we are to look for the earliest traces of the practice of reducing iron to the form of a carburet, or as cast iron, I cannot at the present time venture to assert; but as the employment of steel in

fashioning the stones used in the monuments of Proto-Egypt, India, Greece, etc., elsewhere has been shown, that fact alone seems to imply the acquaintance of those ancient nations with the fusion of iron, and leads us to expect that to the East, and not the West, we must look for the beginnings of this art.

In so far as our own country has yet given testimony, the oldest blast furnaces yet recorded are those of which the ruins formerly existed, and may, for aught I know, still exist, in the Forest of Dean, and the age of which Mr. Mushet has computed as belonging to the commencement of the seventeenth century.

It is desirable, in order to avoid the necessity of raising the question hereafter, once and for all to point out that it is not a consequence, because we are unable to assign an earlier positive date for the blast furnace than that above given, that cast iron was unknown before that period; indeed, from what we glean from the historical records, they assure us that it was in considerable use at a much more remote age. And whereas this knowledge might lead some persons to conclude that as the blast furnace constitutes the first step taken in the manufacture of cast iron to-day, it was necessarily the first step taken in ages long past; still, a consideration of certain features of history, coupled with a consideration of what chemistry now teaches, is more than sufficient to convince us that the high or blast furnace is not indispensable to the production of that carburet, however much it is essential, under our current knowledge, at this present period, in order to comply with modern demands for the metal at paying prices.

To indicate how much more ancient cast iron may really be than, so far as I have ascertained, has been noticed during the last quarter of a century, I may mention a process of making steel used by the Greeks, and recorded in the writings of no less an authority than Aristotle, to which I have on a previous occasion directed attention. Aristotle states:—"Wrought iron itself may be cast so as to be made liquid and to harden again."

Obscure as the Aristotelian account of Greek steel-making is, nevertheless when the terms of the fragment are analyzed, and it is placed in juxta-position with other accounts of steel-making appertaining to times long subsequent, it is sufficient to assure us that such iron (although it may not have been specially employed in the art of making castings, but was produced for the purpose of converting bars of wrought iron into steel, by a process of cementation in a bath of metal surcharged with carbon) was known to the Greeks at least as early as 400 years before our era.

Indeed, we may venture farther still—for recent discoveries in India, and the impossibility of explaining Egyptian sculpture in granite, porphyry, diorite, etc., without the use of steel tools, hold out hopes of increasing our acquaintance with the metallurgy of the ancient Eastern world, by special researches into the storehouses of information yet waiting there to be opened up.

After the discovery of Kutub Minar Laht, near Delhi, as well as the huge iron beams in the temple of Kanaruc, and the coming to light of numerous other testimonies, proving beyond doubt the high acquaintance with manufacturing art, which some persons, at least, possessed in the East in ages long past, the cautious observer is compelled to pause ere pronouncing, as is generally asserted, that Western civilization has in all respects exceeded all previous civilization.

It is a question, whether we have attained, in some respects, the position, in certain of the manufactures most important to man, which was at one time reached by the workers of the ancient world; for, while the rate of production has increased as a necessary sequence of the growth of population, and of novel and wider fields of application, yet it is notorious that in too many instances high quality is not maintained.

There is much to be met with in the remains of the Proto-Egyptian, Assyrian, Greek, and Chinese nations, to show their superiority in this respect. And it is to Central Asia, Asia Minor, and Persia, that we must hopefully look for farther light on this subject.

While all the very old examples of iron which we do find are malleable, and from more than one point of view appear to have been produced from ores reduced without fusion, and when inquiring still farther into the most ancient practice of reduction, no country affords conclusive evidence of cast iron having been an established manufactured product—in the sense we find malleable iron to have been therein—yet the col-

lateral evidence as to an extremely early method of making steel, in which the production of cast iron was a *sine qua non*, convinces us of the necessity for exercising extreme caution ere drawing a conclusion.

The next early intelligible account we have of steel making (after Aristotle) throws equal light upon cast iron making. This is to be found in a work entitled "De la Pirotechnia," published at Venice in 1540, by Vanoccio Bizinguccio; and in the somewhat later but better known writings of Agricola, "De re Metallica," published about 1561. Both these authors describe a process of converting bars of malleable iron into steel by keeping the bars immersed for a considerable time in molten cast-iron.

The process, as described by the earlier author, has been translated by Mr. Panizzi,* and I here quote an extract from that translation, showing how the cast iron was produced:

"Steel is nothing but iron well purified by means of art, and through much liquefaction by fire brought to a more perfect admixture and quality than it had before. By the attraction of some suitable substances in the things which are added to it, its natural aridity is mollified by somewhat of moisture, and it is made whiter and denser, so that it seems to be almost removed from its original nature; and at last, when its pores are well dilated and mollified with much fire, and when the heat is driven out of them by the extreme coldness of the water, they contract, and so the iron is converted into a hard substance, which from its hardness becomes brittle. This may be done with every kind of iron, and so steel may be made of all kinds of iron. It is true, indeed, that it is made better from one kind than from another, and with one sort of charcoal than another, and it is also made better according to the skill of the masters.

"The best iron to make it good is, however, that which, being by its nature free from the corruption of any other metal, is more easy to melt, which is to a certain extent harder than other kinds. With this iron is put some powdered marble or other fusible stones, in order to melt together. By these it is purged, and they have, as it were, the power of taking away its ferruginosity, of constricting its porosity, and of making it dense and free from cleavage.

"Now, to conclude, when the masters wish to do this work, they take of that iron pressed through the furnace or otherwise, as much as they wish to convert into steel, and they break it into little bits; they then prepare before the operation of the forge a circular receptacle, about a foot or more in diameter, made of one-third clay and two-thirds small coal, well beaten together with a hammer, well mixed, and moistened with so much water as will make them keep together when squeezed in the hand; and when this receptacle is thus made, in the same way as they make a hearth, but deeper, the aperture is prepared in the midst, which should have a little of the nose turned down, so that the wind may strike in the midst of the receptacle.

"Then, when all the space is filled with charcoal, they moreover make round about it a circle of stones or soft rock to keep in the broken iron and the additional charcoal which they put upon it, and so they fill it up and make a heap of charcoal over it.

"Then, when they see the whole mass is on fire and well kindled, especially the receptacle, the masters begin to set the bellows to work, and to put on some of that crushed iron mingled with saline marble and with pounded clay, and with other fusible and not earthy stones; and so melting this composition by little and little, they fill up the receptacle so far as they think fit; and having first formed with the hammer three or four lumps of the same iron, each weighing 30 or 40 lbs, they put them hot into that bath of melted iron (which bath is called by the masters of the art 'the art of iron'), and they keep them thus in the midst of this melted matter with a great fire about four or six hours, after turning them about with a rod as cooks do victuals, and so they keep them there, turning them again and again, in order that all that solid iron may receive through its porosity those subtle substances which are found to be within that melted iron, by virtue of which the gross substances which are in the lumps are consumed and diluted, etc., and the lumps become softened and like a paste.

"When they are seen thus by the experienced masters, they judge that the subtle virtue of which we have spoken has

* Percy's "Metallurgy: Iron and Steel," p. 807.

thoroughly penetrated; and taking out one of the lumps which appears best (from their experience in testing), and bringing it under the hammer, they beat it out, and then turning it suddenly as hot as they can into the water, they temper it, and being tempered they break it, and look to see if the whole of it has in every particle so changed its nature as to have no small layer of iron within it; and, finding that it has arrived at that point of perfection which they desire, they take out the lumps with a large pair of pincers, or by the ends left on them, and cut them into small pieces of seven or eight each, and they return them to the same bath to get hot again, adding to it some powdered marble and iron for melting to refresh the bath and increase it, and also to restore to it what the fire may have consumed, and also that that which is to become steel may, by being immersed in that bath, be the better refined; and so at last, when they are well heated, they go and take them out piece by piece with a pair of pincers, and they carry them to the hammer to be beaten out, and make rods of them.

"When this is done, being very hot, and almost of a white color from the heat, they cast them all at once into a stream of water as cold as possibly can be had, of which a reservoir has been made, in order that the rods may be suddenly cooled, and by this means get the hardness which the common people call temper, and thus it is changed into a material which hardly resembles that which it was before it was tempered. For then it was only like a lump of lead or wax, and by tempering it, it is made so very hard as almost to surpass all other hard things; and it is also made very white, much more so than is the nature of its iron, even almost like silver, and that which has its grain white, and most minute and fixed, is of the best sort.

"Among those kinds which I know of, that of Flanders, and in Italy that of Valcamonica, in the territory of Brescia, are very much praised; and out of Christendom, that of Damascus, that of Caramenia and Lazzimino (?), as well as that of Agiambi (?)."

The same process is described by Agricola; but it is worthy of remark, as stated on the authority of the elder Mushet, that nowhere does he describe a process by which cast iron was obtained and applied to foundry purposes.

In India, near Trincomalee, steel (wootz) is still made in the same manner, its manufacture being confined to a few families in that neighborhood, and altogether unknown to the common steel-makers of Salem, a distance of only 70 miles. The cast iron used in this case is obtained from a small blast furnace, about 8 feet high, and tapering from 18 inches diameter at the bottom to 9 inches at the top. The iron flows out, of a grey quality, but without perfect separation, as the cinders produced contain a good deal of iron.

With regard, then, to the production of cast iron in the most ancient low furnaces, it was practicable with ores easily fusible when in presence of large quantities of flux and a great excess of charcoal. The former would preserve the metal from oxidation, whilst it was allowed to remain a sufficient time in contact, to take up a maximum quantity of carbon from the latter. But, as the temperature in such furnaces was low, the slag of necessity contained a large proportion of the iron, and except with the most easily fusible ores, the process very slow; indeed, almost impossible.

With this certainty before us, however, of the possibility of producing cast iron even in the oldest known types of furnaces, coupled also with the well ascertained fact of the use of iron and steel by Greeks, Indians, Ancient Egyptians, and Assyrians, it is impossible to say how far back we may carry the date of the discovery of cast iron. But it is not, as I have already pointed out, to be inferred that the blast furnace has any claim at all to antiquity; on the contrary, I have collected together the foregoing evidence with the object, amongst others, of avoiding any misapprehension on that point.

M. Verlit says that cast iron was known in Holland in the thirteenth century, and that stoves were made from it at Elass in 1400 A. D. According to Lower, the first cannon of cast iron was manufactured at Buxteed, in Sussex, by Ralphe Hogge in 1543. It is recorded, however, by others that the first iron guns cast in England were made in London, in 1547, by Owen. In 1595 the art of iron casting was so well understood that John Johnson and his son Thomas had by that time "made 42 cast pieces of great ordnance of iron for the Earl of Cumberland, weighing 6,000 pounds or three tons apiece."

Agricola, too, who died in 1494 A. D.,

seems to have been acquainted with cast iron, for he writes: "Iron melted from ironstone is easily fusible, and can be tapped off." So that, although he does not appear to say anything as to the method by which such cast iron was produced, it nevertheless is evident, when we consider the large extent to which cast iron was probably then employed for guns, and doubtless other purposes, that the blast furnace was at that time in existence, though on a very small scale.

It had probably grown out of the Catalan, and through the Blaseofen, or Osmund, to the German Stückofen, in which cast or malleable iron was produced as required, by varying the proportions of the materials constituting the charge.

Percy says:—Between the Luppenfeuer, or Catalan furnace, and the Stückofen, German metallurgists place a furnace of intermediate height, which they designate Blaseofen and Bauernofen. This furnace was formerly employed in Norway, Sweden, and other parts of Europe; and though a century may have have elapsed since it became extinct in the first two countries mentioned, yet to this day it continues in operation in Finland. "Osmund" is the Swedish word for the bloom produced in this particular kind of furnace, outside of which consists of a timber casing, and the inner part a lining of refractory stone, the space between them being filled with earth.

The Osmund furnace is used for reducing the hydrated sesquioxide ores (lake or bog iron ores) found in the lakes and rivers of some parts of northern Europe, and in Finland, is stated at the present day to be working side by side with the modern blast furnace.

The Stückofen would appear to be the last stage of transition from the low to the high furnace, into which it ultimately became merged altogether when the discovery was made that the ore was therein more completely reduced. The variety of purposes to which it was found the pig or sow metal could be applied, increased the demand for cast iron to such an extent as to induce the indirect method of reduction to be carried out on a large scale. It will therefore be unnecessary in this paper, which deals with cast iron and the blast furnace as its principal subjects, to refer farther to the pre-existing low furnaces.

Regarding the Stückofen, then, or high bloomery furnace, it has been correctly described by writers on metallurgy as a Catalan or low furnace, extended upwards in the form of either a circular or quadrangular shaft. In Germany this furnace is also known as Wulsofen, the reduced metallic mass resulting from the operations being designated "Stück" or "Wulf," hence the Stück or Wulsofen—Salamander furnace—for the following particulars of which I am indebted to Professor Osborne's treatise, who, in a paragraph preceding the extract, significantly terms this the "transition furnace," which might be used for the production of cast iron or malleable iron at will, by varying the constituents of the charge and the intensity of the blast. "Salamander" is the term now given to the mass of half pure iron, which results when the molten mass of a furnace chills before it can be regularly tapped off into pigs. It is difficult to melt, and is sometimes largely malleable iron. The present may have originated from the earlier use of the word as applied to this furnace.

The Stückofen furnace is (according to Osborne) at present very little in use. A few are still in operation in Hungary and Spain (1869). At one time they were very common in Europe. The iron produced has always been of a superior kind, favorable for the production of steel; but the manipulation which this oven requires is so expensive that it has caused its suppression.

The furnace is generally from 10 to 16 ft. high, 24 in. wide at bottom and top, and measures at its widest part about 5 ft. There are generally two tuyeres (one, however, is frequently used) and at least two bellows and nozzles, both on the same side. The breast is open, but during the melting operation it is shut by bricks; this opening is generally 2 ft. square. The furnace may be heated before the breast is closed; after which charcoal and ore are thrown in. The blast is then turned into the furnace. As soon as the ore presses the tuyere, iron is deposited at the foot of the hearth; when the cinder rises to the tuyere, a portion is suffered to escape through a hole in the dam. The tuyeres are generally kept low upon the surface of the melted iron, which thus becomes whitened. As the iron rises the tuyeres are raised. In about 24 hours, 1 ton of iron is deposited at the bottom of the furnace. This may be ascertained by the ore put into the furnace.

If a quantity of ore is charged sufficient to make the necessary amount of iron for

one cast, a few dead or coal charges may then be thrown in. The blast is then stopped, the breast-wall removed, and the iron, which is in a solid mass, in the form of a salamander or "stück-wulf," is lifted loose from the bottom by crowbars, taken by a pair of strong tongs, which are fastened on chains suspended in a swing-crane, and then removed to an anvil, where it is flattened by a tilt-hammer into 4-in. thick slabs, cut into blooms, and finally stretched into bar iron by small hammers. Meanwhile, the furnace is charged anew with ore and coal, and the same process is renewed.

By this method good iron as well as steel may be furnished. In fact, the salamander consists of a mixture of iron and steel; of the latter, skilful workmen may save a considerable amount. The blooms are a mixture of fibrous iron, steel, and cast iron. The latter flows into the bottom of the forge fire, in which the blooms are reheated, and is then converted into bar iron by the same method adopted to convert common pig iron. If the steel is not sufficiently separated it is worked along with the iron.

This would be a very desirable process, on account of the good quality of iron which it furnishes, if the loss of ore and waste of fuel it occasions were compensated by the price of bar iron. Poor ores, coke or anthracite coal, cannot be employed in this process Charcoal made from hard wood, and the rich magnetic, specular, and sparry ores, are almost exclusively used.

It is obvious that the conditions necessary to the production of cast iron, viz.:—a column of materials which gradually become increased in temperature during their descent, exposed to reducing gases, and latterly, to prolonged contact in the reduced state to carbonizing matter, obtained in this furnace. The result frequently was, that, when intending to produce malleable iron at once, the lump was so much carbonized, owing to excess of carbonizing materials, that it had to be submitted to a decarbonizing process before it could be hammered.

Experience in working the Stückofen proved it to be extremely wasteful of fuel; and about 1840 it was to a great extent abandoned in Carniola, Carinthia, and Styria, although still worked in Germany and Hungary to a limited extent (Karsten).

In some cases a throat was added to the furnace, of a gradually widening form; this gave facility in charging. The tuyere was placed about a foot above the hearth bottom; but as the furnace continued in operation, this distance became increased, by reason of the disintegration of, or the wear of, the hearth (silicious conglomerate), which we learn influenced the yield and quality of the iron as well as the quantity of charcoal consumed.

The Stückofen sometimes increased with a regular taper throughout the entire height of the shaft, being broadest at the bottom, and both rectangular as well as circular in horizontal section. The tuyeres were sometimes made of clay, at others of copper, situated at different points of the furnace; and when in the breast, the bellows had to be removed before the lumps of reduced iron could be withdrawn.

As the demand for cast iron increased, the Stückofen was gradually replaced by the Blauofen (by some authors termed the "blue furnace."—Fr. "*Fourneau bleu*"), in which cast iron alone was produced, but it still retained its place for the direct production of malleable iron. At first malleable iron was also produced in the Blauofen, which was then, it would appear, simply a tall Stückofen, eventually, however, becoming increased in height to from 20 to 25 feet, in which case it was capable of producing cast iron only.

In working these furnaces for the production of malleable iron, the slag was allowed a constant escape, so that the lump of metal in the hearth might be exposed to the action of the blast, which prevented it from becoming carbonized to excess; at other times the slag was allowed to accumulate, thus protecting the metal from the decarbonizing action of the blast, after it had become carbonized in passing through the lower part of the furnace, and therefore producing carbonized or cast iron.

The Blauofen, as in common use on the Continent, may be kept in blast for three to six months, or even longer, after which the hearth widens, and interferes with successful operations.

In working with this furnace, the practice is to heat it by a fire, after which the breast previously open is closed; it is then filled to the top with coal and iron ore, which are renewed as the charge sinks. The tuyeres are about 14 in. above the hearth, which slopes towards the breast.

This furnace requires rich ores and a plentiful supply of charcoal; it produces good pig iron, as well as a metal specially suitable for steel, sometimes called steel-metal, and said to be that from which German steel (shear steel) is made. The management of the Blauofen is simple, and the furnace is cheaply constructed.

From the preceding remarks we have become familiar with the earliest known form of the blast furnace, which, originating in the Stückofen, or high bloomery, of some 95 cubic feet capacity, passed into the Blauofen of some 500 to 600 cubic feet. Without following its progressive development minutely through the furnaces in the Hartz, Silesia, Prussia, Sweden, Great Britain, and America, we may come down to our own age, and now find furnaces in the Cleveland district of the enormous capacity of 20,000 to 30,000 cubic feet, or about 280 times that of an early Blauofen.

INDIAN ENGINEERING.*

From "The Builder."

In these able and interesting lectures some idea is given of the physical features of India, its climate, its people, and of the peculiarities of Anglo-Indian life. The author then proceeds to say something of the Government, and the great Department of State by which public works are executed, and of the special duties and probable career of the Royal Engineer officers who are there employed; and passes on to the materials and modes of construction with which the engineer is called upon to deal, and those specialties which distinguish his work from English practice.

Of the state of the arts and manufactures in India some judgment may, as the author remarks, be formed by an inspection of the beautiful specimens collected in the Indian annexe of the International Exhibition.

Some of the once famous Indian manufactures, he states, have almost disappeared in modern times, such as the Dacca muslin, of which it was said that a full-sized dress-piece could be drawn through a finger ring. Native architecture, too, of the present day is tawdry and meretricious. But Cashmere is still famous for its wonderful shawls, in which we know not which to admire most, the beauty of the fabric or the exquisite patterns and harmonious contrast of colors; Agra still executes that beautiful inlaid stonework, which is yet only one of the wonders of the Taj Mehal; Delhi and Benares send gorgeous embroideries, heavy with gold and rich in coloring; Cuttack furnishes its exquisite silver filigree-work; Sealkote, its steel inlaid with gold in arabesque patterns; Bombay, its massive and curiously-carved ebony furniture. But art can never attain to its highest development in the absence of a healthy national life, and it is to former ages we must turn for structures like some of the Hindoo temples, or the great mosque at Delhi, or "the Dream in Marble" at Agra (the Taj Mehal), and even the artistic manufactures named are legacies from the past, that are apt to degenerate at the present day into a grotesque copying of European designs.

Yet there is an indwelling spirit of artistic grace in the East that will not easily die, which is seen in the instinctive choice of colors in the clothes of the very poorest on a holiday festival,—in the shape of the commonest earthenware utensils,—in the very salutation of the poorest peasant in the fields.

The work of an Engineer officer in India, as in England, is of a very miscellaneous description. Every work is estimated for previously to sanction by the executive engineer, and the estimate, after being checked by the superintending engineer, is forwarded to his chief for sanction, who, if he approve the design and estimate, recommends it for sanction by the local government. or, in case of a large work, forwards it on to the supreme government with his own remarks. If not satisfied with it, he may return it for revision or explanation.

When a work is sanctioned and ordered to be commenced, the money being also forthcoming for it in the Budget, the executive engineer goes to work. In the large Presidency towns, and a few of the more important stations, he may get the

*India and Indian Engineering, three lectures delivered at the Royal Engineer Institute, Chatham, by Julius George Medley. Published by Messrs. Spon, London.

work executed by contract; but, as a general rule, he will have to be content with procuring his materials by contract, and perhaps getting his earthwork done in this manner. For the rest, he will have to employ daily paid laborers, and occasionally may have to import laborers from other districts, to organize them into gangs, provide them with tools, and arrange for their food, water, and temporary shelter. For this he has the assistance of his European overseers, native sub-overseers, and *mistrees* or head-artificers.

The European overseers are nearly all non-commissioned officers or privates who have volunteered from the various regiments in India for the Public Works Department, and have been trained at the Roorkee College. They are allowed to wear plain clothes, and are of course struck off all military duty. As a rule, they are hard-working, intelligent men, and many of them are most valuable subordinates, but they are generally deficient in practical knowledge, are not very conversant with the language, and are but too often given to drink.

The native sub-overseers have also been trained at Roorkee, and are generally good draughtsmen, surveyors, and estimators; but they are drawn from the trading, instead of the working classes, have no practical experience, and lack physical stamina.

The *mistrees*, or native head masons and carpenters, are generally intelligent and good men, quick to learn and easily managed, but few have any theoretical knowledge.

The native laborer is patient, docile, and lazy, never drinks, and is easily managed by any one who understands him.

There are many varieties of stone in different parts of India, and it is employed in the various forms of ashlar, rubble, etc., very much as it is in Europe. Granites, limestones, and sandstones are extensively used in the localities where they occur, but the cost of carriage over bad roads to distant places necessarily restricts the employment of this material. In Southern India, laterite, a clay-stone, is extensively used, being easily worked, and becoming hard by exposure to the air. In Upper India, Delhi and Agra are famous for their red sandstone, and Jyepore for its white marble, of which the Taj and other famous buildings are constructed. Bombay has also many varieties of stone, notably the Poreebunder limestone. Allahabad has some fine quarries of sandstone, of which the new Government Buildings have been constructed, and Colonel Medley recommends to notice the account of the working of the Purtarpore Quarries, in the professional papers on Indian engineering, as giving much practical information. Slate is generally scarce and inferior, but some fine quarries have lately been opened out at Dalhousie, and in the Khuttuck Hills, in the Punjab.

There is a kind of soft stone called moorum, found in Central and Western India, which, though almost useless as a building material, is extensively employed for road metalling. Kunkur, too, is quite an Indian specialty, though it is almost entirely confined to the north-western provinces. It is a peculiar kind of oolitic limestone, found in beds just below the surface, and is of two kinds; one adapted for building purposes, in which it strongly resembles artificial concrete; the other answering admirably for road metalling, for which purpose it is broken into lumps about the size of an egg, drenched with water, and then rammed until perfectly smooth, after which it is allowed to dry before the traffic comes on it.

The manufacture of artificial stone by Ransome's process has been tried at Bombay on a small scale, but not with success in an economical point of view.

In the greater part of Upper India, and over much of the rest of India as well, *brick* is the chief building material, and there are few engineers in India who will not have much to do with brick making. The lecturer therefore strongly recommended his hearers to make themselves well acquainted with the latest improvements in the art, at the same time bearing in mind certain Indian specialties, which will limit the use of many of these methods. These are the cost of carriage, the general absence of coal fuel, the dearness of other fuel, the absence of skilled subordinates, and the disinclination of natives to be driven out of their own customs, and to try experiments.

There is plenty of good brick-earth to be found, but the cost of carriage prevents the same care being taken as at home in the selection and admixture of clays. The clay is often tempered by hand, and then taken straight to the moulding-table; but pug-

mills are now pretty common, worked by bullock power. The bricks are usually sand-moulded, and are made of the English size, and stacked in temporary sheds to dry. Brick-making machines have occasionally been tried; but their expense, the difficulty of repair, and the cheapness of hand labor, have always driven them out of the field. Hollow bricks, too, are never seen; and as the author thinks they would be found to be much cooler in the walls of buildings than solid bricks, he would recommend any one to acquire information of their manufacture and cost.

Colored bricks are nowhere used in India, and their absence is much to be regretted, for they would be most useful both for architectural ornamentation and for floors and similar purposes. The proper clays, on which the colors depend, are found in some parts of India; and careful search would doubtless bring to light others; but here again we are met by the fact that their manufacture requires skill and capital, which are not found on the spot, and would have to be imported. The same remark applies to terra-cotta and encaustic tiles, which would be admirably adapted for Indian use.

Good ordinary bricks are generally procurable in India, if only proper care be exercised, and a fair price paid for them. The bricklayers require close watching, and often systematic instruction in the all-important subject of bond; for the common native brick is very small, and laid in quantities of mortar with little care about bond; so that native walls are really masses of concrete.

Tiles are extensively used in India for roofing purposes, and they are often very badly made.

The subject of limes and cements is a very important one in India. Lime is obtained from the limestone boulders found in hill torrents, from kunkur, from beds of marl, or rather calcareous tufa, and from limestone *in situ*. It is burnt with wood fuel, sometimes in the open, generally in conical kilns, and is mixed with sand, burnt clay, or brick-dust, and sometimes other ingredients, to form mortar in the usual way. The best lime is that procured from boulders, which when mixed in the proportion of one part lime to two parts of *soorkee*, or pounded brick, forms an excellent mortar for hydraulic works. Kunkur lime, as a rule, is simply mixed with sand. When lime is burnt with *oopla*, care must be used in sifting and separating it from the ashes of the burnt fuel, otherwise, of course, its strength will be greatly impaired. Artificial cements have scarcely hitherto been made or used in India.

Concrete is not very much employed, though it has attracted a good deal of attention lately; and some of the works on the new Sirhind Canal were designed to be built almost entirely of it, such as arches of 40 ft. span. Indeed, with an abundance of excellent lime, and a great scarcity of fuel, it seems curious that it has not been more extensively used. Concrete blocks were recommended for the great weir over the Ganges, by the Ganges Canal Committee, to be composed of shingle, sand, and lime; and if proper apparatus be used for testing the quality of the lime, there seems every reason to anticipate economy and good work from such a mode of construction.

Lime is also used in stuccoes and plasters much as in England. Madras is noted for this work, where the very beautiful *chunam* plaster for interiors of rooms, is as smooth, hard, and polished as marble. Coarse sugar and pounded egg-shells are mixed with these more expensive plasters.

Of timbers there is an immense number in India occasionally used; but practically engineers are restricted to a very few varieties, which are the only ones procurable in any quantity. In the Punjab, for instance, the deodar (*Cedrus Deodara*) is the principal wood employed, being nearly identical with the famous cedar of Lebanon. It is found in the Himalayan forests. In Burmah and Western India, teak is the principal wood; its many excellent qualities are well known. Other common timbers are the mangoe, used only for planking or furniture, and readily attacked by insects; the sissoo or sheeshum, a hard, strong, but crooked wood, in general request for many purposes, especially furniture, as it takes a beautiful polish; the keekur or babool, an acacia, a very hard, tough wood, much used for carts; the famous Bombay black-wood, of which some beautiful specimens of carved furniture are to be seen in the Indian Court of the International Exhibition; the toon, an inferior mahogany; the sandal-wood, which has a strong perfume; and many others.

Timber in India is generally seasoned by

the air or water process, and is occasionally kyanized or Burnettized. Well-seasoned timber stands the climate well if carefully protected from white ants, those pests of the East. For this purpose, the ends of beams fitting into walls are generally charred and tarred, or the timber is soaked in a solution of sulphate of copper; but the best preservative is careful'y to prevent any earth or mud from coming in contact with it. Wooden posts buried in the earth will very soon be useless.

The Indian carpenters are generally very fair, and sometimes very clever workmen, though they *do* squat on the ground, and hold a piece of wood with their toes while they work the drill by means of a bow and string with their hands.

Wages, of course, vary more or less; but the pay of a common laborer all over India may be fairly set down at 2 annas, or 3d. a day, and of an ordinary mechanic at 6d. to 7½d., with which he finds himself in everything. A *beldar*, or navvy, will get 4½d., and a skilled carpenter or mason from 9d., to 1s. These wages seem very low compared with English prices; but the men all do far less work than an Englishman; thus, the lowest estimated rate of common earthwork is now about 5s. per 1000 cubic feet, which is at the rate of 50 cubic feet only per day for each man of the gang employed.

Good ordinary brickwork will cost about 40s. per 100 cubic feet; ashlar, about 2s. per cubic foot; timber work, 7s. per foot, "wrought and put up."

Taking into consideration the price of food, and other things, Colonel Medley reckons the difference in the value of money employed in constructing public works in India and in England as 1 to 4, *i. e.*, that a work costing, £10,000 in India would cost £40,000 in England.

We had been led by the accounts of some recent works to a different opinion.

BRIDGE PINS.*

By Prof. De VOLSON WOOD.

From "The Railroad Gazette."

The author makes a serious attempt to solve this problem in a purely theoretical manner. He shows that he is not only familiar with the theory of elasticity in its more ordinary aspects, but also in its more refined forms. He has unlimited confidence in the theory of elasticity as applied to this or to any similar case; "for," says he, "a pin is nothing but a beam, and since a great variety of experiments made on beams prove that within the limits of elasticity the theory adopted is not less correct than of the law of gravitation to the movements of the planets." (Page 21.) The law here referred to doubtless is, that the elongations or compressions of an elastic body are directly proportional to the straining forces. If this is the law referred to, we have only to say that we supposed that most experimenters found peculiar freaks in the law, and that a theoretical limit of elasticity could not be assigned. In some cases the elongations were proportionately greater for small strains than for those ordinarily used in practice; and in many cases the law was so irregular that no definite law could be assigned. See, for instance, the results of experiments made by Hodgkinson, in England, and Wade and Rodman in this country, and also the very delicate experiments made upon the material of the Illinois & St. Louis Bridge, also the final remark, on page 571, of Weisbach's "Mechanics of Engineering," vol. i. (new edition). We do not intend to question the practicability of the law, but we had not before supposed that it was positively as exact as the law of the inverse squares.

Indeed it appears to us that we should not expect to find that the law of perfect elasticity was rigidly exact when it applied to materials in construction, since they are not perfectly homogeneous. The law of perfect elasticity, however, does not give practically correct results when kept within the so-called limit of elasticity, and so far as the problem before us is concerned, the preceding remarks have very little force.

Mr. Bender's article is the first attempt, so far as we know, to determine the dimensions of a pin in accordance with the theory of perfect elasticity. The analytical part is thorough and comprehensive, and it is no

* Proportions of Pins used in Bridges. By Charles Bender, C. E. (New York: D. Van Nostrand.

objection to it that it involves a knowledge of the higher calculus. If the subject demands it, we can say nought against it.

Shall we consider the problem solved? We have held that in all cases where the forces which tend to destroy a structure are necessarily complex, and the parts concerned involve conditions which have never been subjected to experiment, the safer way is to experiment first; or, if we analyze first, we should subject our results to an experiment before practical men use them. The cases are too numerous of failures on account of following theories in untried cases. The fault was not with the theory as used, but on account of the omission of important elements in the theoretical consideration of the problem. A perfect theory which will involve all the elements of the problem must necessarily lead to a correct result, and although we can to-day solve problems in regard to beams which could not be fully solved a few years since, yet any one familiar with the "history of the resistance of materials" knows that theory and experiment struggled together, each aiding the other step by step until we have reached our present knowledge. The main question with us now is: Are the conditions which have been assumed in Mr. Bender's paper so unquestionable as to force us to the conclusion that the problem is satisfactorily solved, and hence that all further experiments are needless? Mr. Bender is so much more of a master of the theory than we pretend to be, that we can do but little more than call attention to such points as attracted our attention in the perusal of the paper.

In establishing the fundamental equation, it is assumed that the transverse shearing stress is uniformly distributed over the transverse section (page 6). Those who do not understand the theory of transverse shearing in *bent* beams may think that this hypothesis is sufficiently evident in all cases; but Mr. Bender shows in a very concise way (page 27) that in the case of flexure the shearing strain is greatest at the neutral axis, and nothing at the surface. Indeed, he makes the general statement (page 24) that "the theory of flexure teaches that the shearing strain is not uniformly distributed over the cross section." He considers the pin in a state of flexure, but assumes that the transverse shearing is uniformly distributed over the cross section.

In order that the transverse shearing should be uniformly distributed, the pin must fit the bearings (page 5), and yet in practice the play in the pin-hole usually exceeds 1-64 of an inch (page 15). In order, therefore, that the law of strains shall be definitely known, who shall determine how little play is allowable in order that the pin shall be considered as practically fitting; and when it has a play, who shall determine how much play, in order that the law of strains shall be that of a beam under flexure?

The author evidently recognizes these difficulties, for he states (page 15) that "for simplicity it is well to assume that this pressure is uniformly distributed over the diameter of the pin, until at least the effect of the 'play' in the hole has been directly determined by a large number of experiments upon impact." The assumption is then made for simplicity. Again (page 6) he says: "The pressure of a pin with play first will be concentrated at a point, but under the load a set will take place and the pressure be more uniformly distributed over the diameter. The law of this distribution is very complex." "The importance of the least practicable play in the pin-hole is evident."

We thus see that it is difficult to determine just what law should be assumed in any practical case; and although the assumption made by the author may be not only the most simple, but also the nearest correct, yet those who look upon such problems from a practical standpoint, and are not able to follow the analytical reasoning, may distrust the results when they learn that such slight modifications lead to such different hypotheses.

But in regard to the analysis we are not quite clear. Assuming that the pressure is uniformly distributed over the cross section,

Let Ax=the pressure per square inch.
Let D=the diameter of the circles, and
Let E=the cofficient of elasticity.

Then will the depression of the lower half of the pin be $\frac{d\,\Lambda\,x}{2\,\mathrm{E}}$. This is doubtless true for a unit of width at the centre A; but how is it for a strip at B, where the depth is not $\frac{d}{2}$. It is true that in the analysis no distortion of the pin is assumed; still when the pin fits the hole it is evident that the vertical pressure at B is not the

same as at A, and the normal pressures at the two points also differ; and it does not appear quite evident, on account of the variable compressive strains on the bearing surface of the semi-circumference, that the formula given for the depression is sufficiently exact, but for a square or rectangular pin it is sufficiently exact, although here we know that as soon as there is perceptible compression there will be a distortion of the angles.

Our difficulties are mainly in establishing the fundamental equation. After that is determined, the analysis takes its natural course.

After finding, as he does for the example assumed, that the maximum pressure is 12,115 lbs., we might ask how this is to be modified (if at all) by the tension on the upper side of the pin due to flexure.

In the investigation thus far the effect of the eye-bar has been neglected. If the pin fits the hole in the eye-bar, will not the eye-bar tend to prevent flexure, and thus modify the strains?

But we will not follow this further. We admit that our course is a pulling down process without offering a substitute. We cannot, however, leave the subject without saying that we supposed that the chief object of the English experimenters was to find the proper proportions of the eye-bar. The pin could easily be made strong enough, but the eye yielded sooner than the bar, and it was found that the pin (especially when large) should be unnecessarily strong in order to give the proper proportions about the eye when compared with the bar; and, although experiments, when carried to ultimate strength, might fail to give the proper proportions for great durability, they at least seem to indicate the weakest part of the eye, and thus indicate in what direction the correction should be made.

EXPERIMENTS IN TRACTION ON THE LARMANJAT RAIL.*

By TRESCA.

M. Larmanjat has for some time been engaged in the construction of iron tracks of a single rail; the aim being to reduce the resistance met in ordinary tracks, while employing the adhesion of the locomotive wheel to overcome steep grades.

The writer has made experiments upon one of these tracks in order to determine the coefficients of traction; and also the distribution of pressures, which vary with circumstances, and are in a degree within control.

The train is chiefly carried by two flanged iron wheels, one before the other, giving rise to a relatively feeble traction. Two lateral wheels run upon the ground, but they bear only a part of the load, which rests now on one side, now on the other, as the centre of gravity oscillates; this oscillation depending on the transverse profile, the distribution of the load, and the amount of compression of the springs.

The track was hollow, being made of iron rails with plates placed in juxtaposition; probably the results would be more favorable on raised rails. The object in view is to carry the train as much as possible on this rail.

The locomotive is borne equally on four wheels; two guide wheels on the central rail, with little traction; two adhesion wheels, running on the ground, and carrying a certain portion of the load sufficient to cause adhesion. The variability in the amount of adhesion, according to needs, is the essential feature of the plan; so that M. Larmanjat proposes to draw heavy loads with a locomotive of relatively feeble power. In any case the adhesion should be in equilibrium with the sum of the tractions of the locomotive and the train. We have made our experiments in order to determine as far as possible the measure of traction of the train and especially of the locomotive.

The adhesion wheels are provided with a rim of caoutchouc (Thomson), 11 centimetres thick. The cars were loaded with cast iron, to equal a load of passengers. The weights were as follows:

	kil.
Two large cars, each 2,137 kil.	4,274
Weight of third	1,750
Load equal to 62 passengers	4,380
Three persons	196
Total	10,600

* Translation from Annales du Conservatoire.

The dead weight is $\frac{6024}{10600} = 57\%$

	Kil.
Weight of empty locomotive	6,380
Water in tank and boiler	1,320
Coal	300
	8,000
Difference due to rims of caoutchouc instead of iron	200
Total	7,800

Counting this in the dead weight, we find it to be 75 per cent. of the total load. Dividing by 62, the supposed number of passengers, we get a quotient of 97 kil., which is less than that of ordinary trains; being 400 kil., first class; 225, second class, and 125, third class.

The total length of track was 385.37 m.; of which 325.37 m. were without curve; with a uniform grade of 0.027 m. per metre. Four trips were made; in the three first a large locomotive drew three loaded cars. But in the fourth a small locomotive drew a large car together with the large locomotive. The wheels of the latter were thrown out of gear. In the first portion of the trip they were loaded as in the first three trips; in the second, the whole load, as far as possible, was carried on the adhesion wheels, so as to determine the coefficient of traction.

In the last half of the fourth experiment the load on the central wheels was reduced by about 800 kil.; the remaining 7,000 kil. being borne by the adhesion wheels.

The central wheels of the cars were 0.90 m. in diameter; the lateral 0.70 m., with rim of 0.08 m. in width. The diameter of the central wheels of the locomotive was 0.56 m.; that of the adhesion wheels 1.10 m., with rim 0.23 m. wide.

The draft was registered with a dynamometer, of which the formula is

$$F = 28.87 + 10.42\ y,$$

F being the traction in kilogrammes to each millimetre of the ordinate y. The results are exhibited in the following table:

EXPERIMENTS IN TRACTION.

1st Trip. *Mean Velocity*, 2.64; *Load*, 10.700 *kil.*

	Register of Dynamometer.	Force of Elevation.	Force of Traction.	Coefficients of Traction.
A to *a*	454.42	288.90	165.52	0.0155
a to *b*	479.64	288.90	190.74	178
b to *c*	462.51	288.90	173.61	162
c to *d*	446.70	288.90	157.80	147
d to *e*	465.49	288.90	176 59	165
e to *f*	464.22	288 90	175.32	164
f to *G*	426.50	288.90	137 60	129
G to *H*	536 32	308.85	227.47	212
A to H	464.11	288.90	175.21	164

2d Trip. *Mean Velocity*, 1.10; *Load*, 10.650 *kil.*

A to *a*	431.81	287.55	114.26	0.0135
a to *b*	430.14	287.55	142.59	134
b to *c*	445.67	287.55	158.12	148
c to *d*	388.67	287.55	101.12	95
d to *e*	442.86	287.55	155.31	142
e to *f*	443.27	287.55	155.72	146
f to *G*	584.57	308.85	275.72	259
G to *H*	318.55	117.15	201.40	189
A to H	434.02	287.55	146.47	137

3d Trip. *Mean Velocity*, 1,83; *Load*, 10,600 *kil.*

A to *a*	513.40	286 20	227.20	0.0214
a to *b*	475.16	286.20	188 96	178
b to *c*	477.57	286.20	191 37	181
c to *d*	445 67	286.20	159.47	150
d to *f*	468.49	286.20	182.29	172
G to *H*	464 11	307 40	156.70	148
H to *I*	504 06	116.60	187.46	170
A to *G*	477.54	286.80	191.34	181

4th Trip. *Load*, 7,800 *kil.*

1st Part.—Mean Velocity, 1m.10.

A to *a*	292.39	210.60	81.79	0.0105

2d Part.—Mean Velocity, 1m.00.

g to *g'*	416 49	210.60	205.89	0.0264
g' to *b*	312.29	210.60	101 69	130
b to *c*	329 59	210.60	118 99	153
c to *d*	354 49	210.60	143 89	184
d to *e*	371 90	210.60	161.30	207
e to *f*	339.49	210.60	128.89	165
f to *G*	357.02	210.60	146 62	188
G to *H*	542.69	226.20	316 49	406
I to *M*	282.39	85.80	196.59	252
g' to G	313.14	210.60	131.41	168

By deducting the total force determined in each experiment, the component of the load in the direction of the inclination, we can obtain separately the measure of the force of traction corresponding to the resistance of friction.

In the tables, this resistance has been divided by the load, in order to determine the coefficient of traction.

This coefficient in the three experiments was 0.0164; 0.0137; 0.0181; mean 0.0160, or $\frac{1}{63}$ of the load. The smallest coefficient corresponds to the least velocity; yet this element, varying from one to three, seems not to have had any considerable influence. The coefficient thus obtained is necessarily much higher than that of $\frac{1}{250}$, which corresponds to the ordinary traction on a double raised rail; and even then $\frac{1}{1100}$ of the American rail; but it is much less than $\frac{1}{28}$, which would correspond to the traction on a MacAdam road in good condition and in good weather.

With regard to the fourth trip, we find results quite different. In the first case a part only of the weight of the locomotive was carried on the rubber wheels, and the coefficient of traction, 0.0105, corresponds to the distribution of this load on the two wheels in the same proportion as in the preceding experiment.

The second coefficient, 0.0168, is due almost exclusively to the resistance of the rubber on the macadamized road; and it differs little from that of the cars. It would have been higher if the wheels had been of the same diameter and width of rim. Comparing with the coefficient found for slower speed, we find an increase from 0.0130 to 0.168.

On the same course of 325 metres were two kinds of track; one, of stringers, over 18.32 m. from *c* to *d*; the other, paved, over 9.70 m. The diagrams showed the following results:

Coefficients of Traction.

	Mean.	Sleepers.	Pavement.
1st trip.....	0.0164	0.0147	0.0165
2d "	0.0137	0.0095	0.0147
3d "	0.0181	0.0150	0.0172
Mean.....	0.0163	0.0133	0.0160
4th trip.....	0.0168	0.0184	0.0207

The stringers diminished the draft notably in the first three experiments, the mean of coefficients falling from 163 to 133.

The pavement made no difference. As regards the rubber bands, it would seem that the stringers were a disadvantage.

Beyond the point G, the diagrams deserve attention, to note the influence of the curve and the grade (reduced to 0.111). The following table shows the results:

Coefficients of Traction.

	Grade of 0m.027	Grade of 0m.029 (curve.)	Grade of 0m.011
1st trip	0.0164	0 0212	.....
2d "	0.0137	0 0259	0 0189
3d "	0.0181	0 0148	0 0170
4th "	0.0168	0 0406	.....

The anomalies here indicated are doubtless due to the short course.

Above the point A, the diagrams show nothing of interest except the maximum ordinate, showing the force at starting. As this never exceeds 54 mille., we infer that the force was never greater than 665 kil.

En resumé we have the following practical results:

1. The coefficient of traction on a grade of 0.027, allowance being made for the work of elevation, is reduced by this system of wheels to $\frac{1}{63}$, reducing the coefficient of traction on macadamized roads 40 per cent.

2. This advantage is lessened as the grade becomes steeper. For a grade of 0.030 the total force would be $0.030+0.016=0.046$; while on an ordinary road it would be $0.030+0.040=0.070$. It would be reduced to 0.67 of its value on an ordinary road.

3. The useful weight of the train was largely reduced by reason of the great proportionate weight of the cars and the locomotive.

4. As regards the locomotive, deducting work due to elevation, we find two altogether different coefficients, one 0.0105, very small; the other 0.0168. Supposing 800 kil. of the total weight to be carried on the rail, and taking a coefficient of 0.01, we find a coefficient for the rubber wheels of 0.0176; probably due to the relatively large diameter of the wheels, viz., 1.10 m.

5. On this grade of 0.027 there was still a large excess of adhesion which might easily have been utilized by carrying a large share of the weight of the locomotive on the driving wheels.

6. The small locomotive, weighing 2,700 kil. and drawing $8,200+2,500=10,700$, weight of locomotive and car, gives an adhesion sufficient to balance the component along the grade of 0.027 m., of $10,700+2,700=13,400$, or 361.60 kil; with traction corresponding to the same load, or $13,400\times0.016=214,40$, in all, 576.80 k.; sufficient to draw on a horizontal rail 576.80:

0.16 = 36.050, or 13.35 times the adhering weight.

Previous experiments on Aveling & Porter's road locomotive showed that on a good ordinary road in fair weather the adhesion corresponded to the traction of a total load of not more than 12 times the adhering weight.

ACCIDENTS TO SUBMARINE CABLES.

From "Engineering."

When a deep-sea cable was long ago talked of as possible to be laid across the Atlantic, there were many wiseacres who shook their heads and prophesied short life to any submarine cable from the voracity of the inhabitants of the deep sea. These opinions found little faith, and were laughed at. Cables have been laid, and for some time the nearest danger was that which happened to the Atlantic cable by the close approach of a large whale whilst paying out was proceeding. Time has gone on, and the wiseacres were after all not so far wrong, for we have now on record several instances of damages to submarine cables by the inhabitants of the sea.

The first appearance of any damage done to a submarine cable appeared to the Levant cable laid by Mr. Newall, who speaks of the destruction to the hemp by a species of "teredo." Mr. Siemens speaks to the same effect, and says: "This cable, which was laid in 1858 and taken up again last summer (1859), was found to be beset by another enemy in the shape of millions of small shell-fish or snails, accompanied by small worms, which had completely destroyed the unsheathed hemp, and eaten some circular holes in the gutta-percha." Professor Huxley wrote as the result of his examination of these shells: "The specimens you have sent me remove all doubt as to the nature of the mischief-maker in the cable. It is a bivalve shell-fish, the xylophaga, closely allied to the ship-worm (teredo), but distinguished from it, among other peculiarities, by not lining its burrow with shelly matter. The xylophaga turns beautifully cylindrical burrows, always against the grain, in wood; and I have no doubt it perforated the hempen coating of the cable in the same way. On meeting the gutta-percha it seemed not to have liked it, and to have turned aside, thus giving rise to the elongated grooves which we see. Nothing is known, so far as I am aware, of the range in depth of xylophaga, so that I cannot answer your inquiry as to whether it is probable that cables immersed in 600 to 2000 fathoms of water would be attacked or not."

In 1860, several portions of cable covered with hemp and steel wire were picked up in the Mediterrannean, off Minorca; these were found in places, and up to deep water, very much attacked by xylophaga, the hemp between the steel wires being eaten away into holes with the regularity and spacing of those in a cribbage-board. As in previous cases, the gutta-percha was penetrated to various depths, but not more than the size of the shell-fish. It was generally considered that the xylophaga did not penetrate, owing to its dislike to gutta-percha; but some persons, at the time, thought there was a great deal of doubt about the point, for there was no sign amongst the great length of cable so damaged, of any dislike, the main sign being that there had been *no time* for further penetration.

That the xylophaga does penetrate gutta-percha to an injurious extent was found to be the case with some experimental wire laid in Kurrachee Harbor; this core was subsequently found to be pierced in numerous places, to such an extent as to destroy the insulation. No such severe case has elsewhere been met with, although xylophaga are now met with in almost every sea and every point where cables have been laid. In the Norwegian cable, we have seen specimens which exhibit more than usual penetration.

It may be generally assumed that a core with a solid sheathing of iron wire, so long as that sheathing remains, is safe against the attacks of these destroyers, but that a core cannot be considered safe as soon as an opening presents itself, for, up to the present time, it is impossible to say where they do not exist. In the recent operations connected with the attempt to repair the

1865 Atlantic cable, a portion of the 1858, or original cable, was brought to the surface. Where the wire sheathing had disappeared it was found that the gutta-percha had been attacked; "for where the core had been bared there are distinct marks of worms, such as one sees in very old hard timber, or in the rich calf binding of old folios in a library."

We have several reports at different times of cables being damaged by the attack of inhabitants of the sea. The Cuba and Florida cable was once damaged by the bite of some large fish, and a similar accident happened to the China cable In the Malta-Alexandria cable a piece of core, from which the sheathing had been worn, was found to be penetrated by being bitten by a shark, pieces of the teeth being left in the gutta-percha, indicating unquestionably the cause.

Some details of a fault which happened some time since to the Singapore cable are interesting. This cable was laid in December, 1870, and the first stoppage occurred in the following March, and was found to be 200 miles from Singapore. The cable was pierced, and pieces of bone were found crushed in the middle of the hole. This specimen was examined for a long time by Mr. Frank Buckland, and it was remarked that the damaged place was caused by piercing, and not by being bitten by the force of a jaw. He accidentally found in his collection a saw-fish, from which he detached the saw, and found that he could make in the cable an incision similar to that which already existed. Mr. Buckland stated that the saw-fish have the habit of penetrating the bottom of the sea in search of food, and giving a backward and forward motion to the species of lance with which they are armed. The extremity of the saw of one of these fishes would become entangled in the exterior wires of the cable; a further brisk movement of the fish would make it penetrate; and, finally, violent struggles would break the saw, after having pierced the cable through and through, as seen in the damaged piece.

Details of a most extraordinary breakdown to the Persian Gulf Cable came to us from Mr. Izaak Walton, the superintendent of the Persian Gulf telegraphs. He relates that "the cable between Kurrachee and Gwador (a distance of about 300 miles) suddenly failed on the evening of the 4th instant. The telegraph steamer, Amber Witch, under the command of Captain Bishop, with the electrical and engineering staff under Mr. Henry Mance, proceeded on the following day to repair the damage, which, by tests taken at either end, appeared to be 118 miles from Kurrachee. The Amber Witch arrived on the ground at 2 P. M. on the 6th, a heavy sea and thick fog prevailing at the time, but the cable was successfully grappled within a quarter of a mile of the fault.

"The soundings at the fault were very irregular, with overfalls from 30 to 70 fathoms. On winding in the cable unusual resistance was experienced, as if it were foul of rocks, but, after persevering for some time, the body of an immense whale, entangled in the cable, was brought to the surface, where it was found to be firmly secured by two and a half turns of the cable immediately above the tail. Sharks and other fish had partially eaten the body, which was rapidly decomposing, the jaws falling away on reaching the surface. The tail, which measured fully 12 ft. across, was perfect, and covered with barnacles at the extremities.

"Apparently the whale was, at the time of entanglement, using the cable to free itself from parasites, such as barnacles, which annoy them very much, and the cable hanging in a deep loop over a submarine precipice, he probably, with a fillip of his tail, twisted it round him, and then came to an untimely end."

This is, without exception, the most extraordinary accident that has happened to any submarine cable that has come within our knowledge, although many strange accidents have arisen. In one case the cable across the river Yar, in the Isle of Wight, was broken by a bullock, which falling overboard, got entangled in the cable, finally breaking it.

The causes of interruption we have alluded to are impossible to provide against, with the exception of the attacks from xylophaga, and it is to be trusted that they will always continue to be of very rare occurrence. The use of silica in the compound now generally applied outside all cables is hoped to be a preventive against the insidious attacks of the persevering shell fish. Enough, however, has been said to show that there are strange elements in the life of a submarine cable.

THE RAPIDITY OF DETONATION.

From "Nature."

A circumstance of singular interest has recently been revealed in connection with the investigations still being carried on with gun-cotton at Woolwich Arsenal. The experiments made with this powerful explosive have now extended over a period of ten years, and although many discoveries of vital interest have been made by Professor Abel, and by Mr. E. O. Brown, who is aiding in the research, the results teach us, before everything, how much more we have yet to learn of the properties of pyroxiline. First of all, the violence of its explosion had to be tamed, then a compressed form of the material was devised, and after that it was shown that, like its sister-explosive, nitro-glycerine, gun-cotton could be violently detonated, if ignited by a charge of fulminate. Gun-cotton, in fact, turns out to be sympathetic, for according to the energy with which it is inflamed, so it responds in its behavior: thus, if gently ignited by a spark, the cotton, in the form of yarn, smouldered slowly away; when set fire to by a flame, it burnt up rapidly; if in the form of a charge it was exploded in a mine or a firearm, it at once resented the shock and replied with corresponding energy, behaving like gunpowder under similar circumstances; while, lastly, if fired with great violence with a few grains of fulminate, it is detonated with as much force and with the same terrible effect as its instigator.

More recently, as many may have heard, our investigators have succeeded in detonating, or in other words, exploding to the best advantage, gun-cotton when in a damp condition; and in this state the explosion is every bit as violent as when the material is dry. This grand discovery is naturally of the utmost impotance, because, although many objections may be advanced as to the danger of storing and using gun-cotton when dry, the most nervous of us would scarcely hesitate to employ it sopping wet. In this latter condition the material is, strange to say, not only non-explosive, but positively non-inflammable; so much so, indeed, that it would be probably as serviceable in putting out a fire as a wet blanket or a damp towel would be. It can neither be inflamed nor exploded when wet; and further, unless one has the key to its detonation—a little fulminate of mercury—it is of no more value as an explosive than so much wet paper pulp. When placed in contact, however, with a fuse of the proper construction and a cake of dry gun-cotton, to start the action, the wet pyroxiline, as we have said before, detonates as readily as when the moisture amounts to but a fraction of a per cent. Moreover, the quantity of water in the material is really of no importance, for it has been found that for submarine mines, compressed cakes enclosed in a fishing-net and thrown overboard with a dry primer and a fulminate fuse, will explode with just as much energy as when confined in a water-tight steel case.

It is in respect to this detonation, and more particularly to the rapidity of its action, that we desire to speak at the present moment. Recent experiment has shown that the rapidity with which gun-cotton detonates is altogether unprecedented, the swiftness of the action being truly marvellous. Indeed, with the exception of light and electricity, the detonation of gun-cotton travels faster than anything else we are cognizant of. Thus, detonation will run along a line of gun-cotton cakes, placed so as to touch one another, with a rapidity only inferior to that of electricity, setting fire to a charge or conveying a signal, if desired, almost instantaneously. Twenty thousand feet, or nearly three miles, per second, is calculated to be its rate of travelling according to Noble's electric chronoscope. In one experiment 42 ft. of the material was fired, and records secured at every 6 ft.; and in this case the results given were most uniform, for the velocity only varied from 19 to 20,000 ft. per second, the ratio of transit being in no instance less than this.

To form an approximate idea of this extraordinary rapidity, it is necessary to call to mind the rates of travelling of other mediums. Light and electricity we may leave out of the question, as these are immaterial bodies. A bullet usually flies at the rate of 1,300 ft. per second, although rifled barrels have been known to project a shot with a velocity of 1,400 ft. Sound is much slower in travelling, for a second of time is required in getting through some

1,100 ft. A quick match of the most delicate construction would probably be longer still in making way, and a train of gunpowder would be left far behind. So it may be safely affirmed, we think, that the detonation of gun-cotton travels more rapidly than any other known medium, with the exception, we repeat, of light and electricity.

It is curious to note that not every detonating or fulminating substance will induce the detonation of gun-cotton. It seems as if a certain number of vibrations require to be set up—a certain key-note to be struck—in order to secure the decomposition of the material. Thus it is found that fulminate of mercury detonates gun-cotton readily, while again it is also capable of being detonated by itself; so that if a line of compressed cakes is detonated at one end by a charge of fulminate of mercury, the detonation is communicated rapidly from one cake to another, until they are all consumed. Nor does the force diminish at all as it runs along the line, as might perhaps be imagined; if this were the case, the detonation set up at the beginning of a line would only run up to a certain distance, and there come to a full stop, as soon, that is, as the vibrations are insufficient to explode the gun-cotton. This, however, does not happen in actual experiment; and, on reflection, it stands to reason that if the first cake of pyroxiline is capable of firing the second one, the ninety-ninth is just as ready to detonate the hundredth. Thus the detonation can be carried along a line of any length, and the force is as powerful and violent at the end as it was in the beginning.

This property of gun-cotton may obviously be put to valuable use both in industrial and military operations. In any case where it is of importance that a series of blasting or mining charges should be fired simultaneously, their connection together by means of gun cotton would insure such a result. True, the same effect could be obtained by means of an arrangement of insulated wires, the charges being detonated simultaneously with the aid of a battery, but such a plan is not always convenient nor practicable. For cutting down palisades, or stout wooden walls, a line of gun-cotton discs exploded in this way would be most efficacious; and a more ready plan of felling timber does not probably exist than that of placing around the stem of a tree a chain or necklace of the explosive in the form of compressed cakes, the detonation of these dividing the trunk as sharply as the keenest axe.

The general results of the working of the railways in Europe for the years 1864–7 have just been published officially. The total length of the lines in working order at the end of 1867 is given at 85,384 kilos.; the total cost of working at 1,431,144,143 f., and the total net revenue 1,474,663,053 f. The expenses exhibit considerable differences, not only in various countries, but in various cases in the same country, and whether the lines were worked by companies or by the governments. The length of lines worked by the latter was only 13,000 kilos. It is only in Baden, Oldenburg, Reuss, and Brunswick that all the lines are worked by the State; and the only countries in which they are entirely in the hands of companies are Anhalt, Austria, Denmark, Spain, France, Great Britain and Ireland, Italy, Holland, Luxembourg, Portugal, and Turkey in Europe. The highest rate of cost of working was in Turkey, where it reached 92.66 per cent. of the receipts, and the lowest in Austria, where it only amounted to 39.09 per cent. The average cost of working by the State was 50.70 per cent. in Germany, and 54.50 per cent. in other European countries; while the cost of working by companies averaged 46.12 per cent. in Germany, and 48.33 per cent in the other nations.

With the exception of Germany and Austria, in which cases the results are not given, France works her railways with the greatest economy; her expenses only amounted to 46.79 per cent. of the receipts, while in England they reached 50.22, in Belgium 53.72, and in Switzerland 50.61 per cent. The difference in the net income between 1864 and 1867 showed an increase in favor of the latter year of 0.76 per cent., and in France alone 1.42 per cent.

The King of Holland has inaugurated the new ports of Flushing, which deserve notice for their commercial importance. They open on one side to the North Sea by the Scheldt, which is navigable for ships of the largest class, even in the winter, when the greater part of the Dutch ports are frozen up; on the other hand, they are connected with the whole European system of railways, and with the navigable canals of Germany.—*Iron.*

THE ENERGY OF ELECTRICITY, WITH ESPECIAL REFERENCE TO ITS MEASUREMENT AND UTILIZATION.

By the Rev. ARTHUR RIGG, M. A.

From "The Telegraphic Journal."

The energy of electricity is being manifested in phases new to men day by day. That which in the early part of the present century was unknown, is now so well known as to win neither surprise nor notice. The telegraph which girdles the earth—the electro-deposition of metals—the light which pales our brightest—the power which melts the most refractory metals—these have been handed down by science to promote the commercial and social welfare of mankind. Propositions better established than that which asserts electricity to be non-producible from sufficiently economical sources, have faded into oblivion. The energies of electricity are manifested whenever there is a molecular disturbance within or amongst bodies. Whenever any change takes place in anything whatever, and amongst any molecules whatever, an electric current is produced, and if not necessarily manifested to us, still it always is present. Probably there is not a single act of our lives, and it may be not even a thought in our heads, which is not associated with an electric current. Kindly understand that the lecture is on the energy of electricity, and, therefore, time must not be occupied in describing instruments. Galvanometers are nowadays made so delicate that if you lay one finger in one trough of salt water, and another in another, and simply tighten the muscles of one arm, a current of electricity passes through the galvanometer and deflects the needle. We usually speak of a galvanic battery as being formed of zinc and copper, or of metals in chemically different relations to a liquid. If, however, you take a piece of ordinary copper bell wire, and connect the two ends of it to the galvanometer, then cut it in two with a pair of scissors, and dip each cut end into salt and water, or put them into your mouth, an electric current passes, and the galvanometer shows that there has been some species or other of molecular disturbance which has caused a manifestation of electrical energy. This energy of electricity becomes kinetic when it is allowed to pass freely. For example, in any bodies that are quiescent it is kinetic, but it is potential when resisted. If, for instance, a current of electricity passes along a wire, and the action is resisted, the wire becomes hot. If it passes through any compound body, as, for instance, water, then it is resisted, and the water is immediately decomposed. Consequently we are dealing with an energy manifested in molecular disturbance, and having both a potential or stored up power, and a kinetic power in motion. The question now is, how is this energy to be measured? Towards the middle of the last century (about 1746) the first electrical machine was made. In 1650, Otto Guericke, to whom we are indebted for the air pump, suggested the scheme, but Hawksbee was the first to make one. His machine consisted of a ball of sulphur, afterwards altered to a ball of glass. The hands were employed to rub it, and a large fly-wheel about six feet high was employed to turn it. Silk threads from the ceiling held what we now call the conductor; and by the exercise of a very large amount of mechanical power they were enabled to get a small spark, to the surprise of all, to the curiosity of many, and the dread of not a few. After that we come to the plate machine, which is arranged, as you are aware, with cushions; still we have those sparks which were supposed to have much energy in them. We then pass on from the glass-plate machine to the vulcanite-plate machine. Sparks pass from the conductor, and are usually charged into a jar of this kind—a Leyden jar. That was first done in the year 1746. The mode in which electricity thus presenting itself was ultimately measured, was by a small jar of this kind, called a unit jar. The state of the atmosphere and other surroundings so influenced the passing electricity that accurate comparisons and conclusions could not be made. Moreover, these jars vary on the surface, and in the character of the glass, and in other ways; consequently this mode of measuring energy must necessarily be a failure. The unit jar, therefore, has fallen into complete disuse. Let us now pass on to the mode of obtaining electricity from chemical action. Before doing so, a phenomenon

should be noticed, which disturbs results very seriously, and which is, at present, not understood. Here is some copper wire, covered with cotton, coiled from end to end, say five or six times along this large bobbin of wood. Within the bobbin is a larger hole than usual. The two ends of this wire so coiled are connected with the reflecting galvanometer. The reflected light from this lamp is now visible and stationary upon the screen. You are aware that motion of that reflected speck of light will be the consequence of electricity passing through the coils of the galvanometer. Now observe that, without either chemical or physical agency acting upon or in contact with the wire, we shall obtain a manifestation of electrical disturbance within the copper wire. Let the end of this steel magnet be introduced within the bobbin, you see that the speck of light immediately moves. Except in this manner, copper does not manifest electrical properties. Again, if the other end of the steel magnet be brought within the bobbin, you see the speck of the galvanometer moves in an opposite direction. Thus may be shown one form of electrical induction. Now, with that phenomenon we are perplexed. This property of induction manifests itself at times and in ways of which we know nothing. For example, if a copper wire were laid upon this floor, and another copper wire were laid parallel to it on the floor below; and if any current of electricity passed through the wire on this floor, the one below would answer to it, although there was not any apparent contact or communication between them. The next stage in obtaining electricity is by means of what is called a galvanic cell. Such a cell usually consists of two different metals, and one or two liquids. Whatever may be the arrangement, the electricity developed may be estimated by the intensity of chemical affinity during the process, and at the time of the measurement. But the whole of this question of chemical affinity must now be assumed, and some of the affinities explained in the last lecture are probably the chemical affinities operating in this cell. A chemical action takes place upon a square inch of one plate, and it is met by an action upon a square inch of the other, therefore on every square inch an action is produced. Between the two plates there is something (say the liquid) which causes the action. It is in fact the presence of this liquid which calls the chemical affinities into play. A word must now be introduced which will often occur during the evening, and it is one which performs an important part in the measurement of electricity of the character which men utilize, *i. e.*, resistance. Indeed, this resistance to the free passage of an electric current is our chief business to-night. Whilst the size of the plates in these cells is increased, the resistance to the free course of the manifested electricity is not decreased. Thus, for instance, from a square inch of one plate there is a current of electricity meeting or co-operating with that developed from a sq. in. of the opposite plate. Whatever may be the energy of the chemical affinity upon 1 sq. in., it is met by the energy of the chemical affinity upon the opposite sq. in. of the other, and that energy has to overcome the resistance of the liquid between them. Now, then, assume that each of these plates is enlarged by the addition of another sq. in. This introduces an additional quantity of liquid, and we have to overcome the resistance of this liquid. It may perhaps make clear what is a difficulty to many minds if an attempt be made to explain how it is that an electrical current which passes when cells are coupled up "in series," that is, one after the other, is more intense than when they are combined as one large single cell. Supposing these two plates, each 1 sq. in. in area, were the only two concerned, therefore there would be a certain resistance to be overcome. The chemical affinity of one such combination not only overcomes that resistance, but leaves a surplus of electricity, which surplus is said to run along the outside wire, and may produce what we call a telegraphic dispatch. Now, suppose that in addition to those two plates, there are two others of the same size and material in a cell behind them. Between these second plates there is also a resistance similar to that between the first two. Those two second plates, however, also produce a surplus. Now as that surplus passes over, it continues its way through the previous plates and wire, and the consequence is that when once the resistance of its own cell has been overcome, the surplus electricity can pass through the other cells without any resistance, and therefore we are enabled to add the surplus of one cell to the surplus of the next, and so on.

Electricity thus, or by other means at our disposal, is now to be measured. This electricity is measured in a very simple way. All the apparatus is here, but as it would take to long too show experiments in detail, perhaps you would kindly accept a statement of facts instead of a visible reproduction of them. In these cells is being produced a quantity of electricity which is to be measured, much as sugar is measured by the pound or liquids by the quart. The way it is measured is either by the chemical decompositions that it can produce, or by the amount of heat it can develop, or by other means, as for instance its effect upon the magnet in a given time. To consider a mode of measurement we must recur to those elements—mass, space, and time. The apparatus on which my hand now rests consists of a wooden ring, about 10 in. in diameter, having coils of copper wire, round it. Within this circular box with a glass top is a small magnetized steel needle. Now, the small steel needle assumes a certain position in consequence of the influence of terrestrial magnetism. Such an influence as this is not unlike a stream of water in a brook upon a short stick, one end of which is tied to a stake by a string. So long as the stream flows steadily past the stick it is retained in the same position. Let a disturbance take place in the evenly flowing water, and the stick will no longer retain either steadiness or direction. Suppose, now, that this needle is retained in a certain direction by the influence of what we may call the stream of terrestrial electricity flowing through the atmosphere of this room. (That such a stream is so flowing through the atmosphere shall be made apparent presently.) From these four cells of a galvanic-battery a current of electricity may be caused to pass along the wire which surrounds this wooden ring. The arrangements are made, and such a current is now passing. What is the consequence? The even flow of that which retained the needle is disturbed, and the needle answers as the stick in the water would have done to the disturbing causes. Clearly the nature and extent of the invisible disturbance may be estimated—indeed measured—by the motions of the visible needle, just as a new position assumed by the stick would measure the disturbing influence on the stream. The promise to let you have proof that there are currents of electricity passing through the atmosphere of this room may now be redeemed. Here is a circular wooden ring, with wire round it as before. You may notice that it can be turned as a looking-glass in its frame. The ends of the wire coiled round it are now connected with the wires of the galvanometer, the mirror of which reflects that speck of light on the screen. The looking-glass mounted ring is placed in reference to the (so-called) current of electricity always passing through the atmosphere, that were there a glass in the frame the current would beat upon that glass. If the frame be turned one-fourth round, then the current will pass parallel to the face of the frame. Or thus:—If the frame of the wire-enclosed ring be placed parallel to the direction of this magnetized needle, then the current of electricity through the atmosphere of this room is passing parallel to the ring. To move it, therefore, from this position to one at right angles to it, it is clear that the circumferential wire must, as it were, cut the stream of electricity, if there be one. Now, so cutting it, there will be a disturbance in the electrical condition of the wire, which may be manifested by a motion of that speck of light. Observe now, that every motion of the frame causes a motion in the needle of that galvanometer, which is placed on a stand far removed from the table on which the motion of the frame takes place. The two experiments now made may satisfy you:—1st. That there is what, for want of another name, we may call a current of electricity passing through the air; 2d. That disturbance of the uniform quiet flow of this current may be caused; 3d. That this needle is sensitive to such a disturbance; and, 4th. You will perhaps accept my word for that which time alone prevents being illustrated, viz., that the amount of this disturbance may be measured by the needle; that is to say, the greater the disturbance the further will the needle be moved from its original position. Telegraphy seems at present to have taken the most important position in the manifestation of the energy of electricity. Telegraphists therefore naturally consider how they can measure the energy with which they deal. The first question that presents itself is what may be called the measure of resistance. It was soon observed that electricity passed along certain metal wires more freely than other metal wires of the same size and length. The observation admitted of a very impor-

tant utilization. For example, suppose the wire now stretched from one end to the other of this room was one mile in length, and that the little apparatus with which electricity is being produced at this end could produce a certain result at the other end. Now, let us take another metallic wire of the same length, and suppose the result produced in this case is much less than in the first. It will be admitted, without any detailed experiment, that by shortening again and again, the second wire may be reduced to a length which permits the phenomenon at the end of the first wire to be repeated at the end of the second. Now measure the second; it is only one quarter of a mile. Try a third and a fourth wire; perhaps they are respectively reduced to one-eighth and one-tenth of a mile. Evidently there is some property in these wires which hinders, retains, or resists the progress of electricity. The property is called "resistance," and is available for very useful purposes. It may here be remarked that perhaps there have been no lectures ever given in this room of a more important and scientific character than a course of Cantor Lectures on electricity by Mr. Fleeming Jenkin. This course commenced in January, 1866, and will be found reported in the "Journal of the Society of Arts," published between the 2d February and the 2d March, 1866 (inclusive). In the experiments which determined what is called "the British Association unit of resistance," electric currents acted upon a very small needle carefully suspended, so that they were enabled to estimate the resistance of the wire in an absolute measure of space and time. That led to the adoption of what is called the "ohm," or "British Association's unit of electrical resistance." In this little glass cylinder there is a coiled length of German silver wire, German silver being used because it possesses great resistance to electrical currents, and that resistance does not change much with change of temperature. This coil constitutes what is called half a British Association unit, which becomes the measure of electrical work, just as the standard pound becomes the measure for weight, or the foot is the standard measure for length. Being possessed of this measure, we have all that is needful for the measurement of resistance, and therefore for measuring electrical work connected with telegraphy. To show the way in which a knowledge of this measurement can be utilized, rather than to enter upon those investigations by which it was obtained, seemed likely to win so much more attention and interest, that these arrangements before you are for this purpose. The intention is to show how electricians determine the distance at which a deep sea cable is broken, so that they can tell how far the fracture is from the shore. Let it be understood that it is the illustration of a principle, and not the nature and modes of dealing with different kinds of "faults," that are to be our concern. There is a wire, which may represent a cable, round the room. In this box there is placed a number of "ohms" arranged in three sets of nine each, so that by moving these pegs a current of electricity can be caused to pass through either one or more of them. Assuming each "ohm" in the first set to represent one resistance, each in the second set ten, and each in the third set one hundred, the consequence is that if a current of electricity passess through all, it would meet with a resistance of 999. If it passed through one of the first set, it would only be one resistance; so that with the moving of these brass pegs there is the power of bringing in any number of ohms required. This flat board, about 3 ft. 6 in. long, with a German silver wire and broad bands of copper divided at intervals, but capable of being put into electrical connection by the insertion of pieces of metal, constitutes what may be called the beam of electrical scales. Resistance, however, is to be measured instead of weight. Along a wire at the back electricity can pass, and when connected with the galvanometer the speck of that instrument serves the same purpose as the pointer of a pair of scales. If the galvanometer speck points to nothing, we assume that there is equilibrium between the resistances at each end of the scale beam. If I put 999 "ohms" in what we may call one scale, and other resistances into the other scale, or that which we may consider as such, then if the current of electricity arranged as provided can pass one of these groups of resistances more freely than the other, the speck of light will be moved. This is the same as though one end of a scale beam were "kicked up." Therefore resistances, which in this case act the part of weights on ordinary scales, must be taken out or added as may be required. This wire running partially round the room represents a cable. The two ends of

this cable are in my hand. Let us assume that we want to measure the resistance the cable opposes to the energy of electricity, and to ascertain the value of its opposing power.

Here is what is usually called a battery, consisting simply of a little salt and water, in a very small tumbler glass. The wires from this battery are so arranged that the current may divide itself between the cable that is round the room and this box of "ohms." In the experiment before you the pegs in the box of ohms read 505; the speck of light is steady; therefore we know that the entire length of cable, of which the two ends are here, also offers a resistance of 505. Before this cable was laid, a comparison with these ohms had been instituted, and it was found (say) that one mile of the cable offered a resistance to the passage of electricity equal to one ohm, therefore there are 505 miles of cable, because there are 505 ohms. Now let us break the cable by cutting the wire. There! one end has fallen to the bottom of this large pan of salt and water. This pan must, for the present, be looked upon as an Atlantic Ocean, one end of the cables is at the bottom of it, and we wish to know how far from the end in my hand the separation has taken place. To compensate for the portion of the cable hitherto used, but now detached, the earth is available; this sheet of copper, in and on the shore of our Atlantic Ocean, is buried. Soldered to the copper is a wire, of which the end is in my hand. There are therefore in my hands the ends of two wires; one, that of the broken cable—the other, that connected with the buried sheet of copper. Let us deal with them as we did with the complete cable. [After various trials the pegs in the box of ohms were so arranged that the speck of the galvanometer was steady.] The speck is now steady, and the pegs read 350. This means that there are 350 miles of cable, or its equivalent. Now, the cable and the earth are the only elements on the one side; and since the earth is as a large reservoir of electricity it offers no appreciable resistance; hence the only resistance is that of the broken cable. The length of this is pointed out as 350 miles; this, therefore, is the distance of the fracture from the shore. How novel and delicate are the instruments employed, how accurate are the measurements obtained, and how marvellous are the uses to which electricity has been applied; yet these are not consequences of a blind rule-of-thumb following of that which has been long known. Patient research, persevering labor, and much thought have not only "put a girdle round the earth," but they promise fair to enter upon and possess electrical territories of vast extent and luxuriant social fertility. When will the people of England recognize this? Echo answers, "When!"

RIVERS AND CITIES.

From "The Engineer."

When Bacon wrote that "final causes are barren" when employed as a means for the interpretation of natural laws, he expressed a profound truth. The interpretation of nature's laws deduced from what we imagine ought to be the end or reason for observed phenomena, may be altogether erroneous, and must be always intermixed with error, because we know so little even of our own world, much less of the universe, viewed as a complete mechanism, that we never can discern the whole reason or cosmical end of anything; and may even wholly misinterpret that end. Nevertheless, there is one use of the appeal to final causes to which Bacon himself has given the sanction of his authority. We may employ them as a means of checking or controlling the correctness or the contrary of the conclusions at which, by other than *a priori* methods, we have arrived for dealing with any complex system of forces such as we find active in nature, by means of such works as those devised by the engineer. The harbor engineer, for example, if he possess wisdom proportionate to his aims, and desires to construct harbors that shall not silt up, or sea defences that shall not be washed away, is compelled continually to employ this line of thought for the final revisal of his designs; he asks himself what are the functions and uses of the winds and tides; what their play on the world's machine; what are the ends and uses of cliffs, beaches, and strands; what are their ends and how do they fulfil these?

For experience teaches that whatever these ends may be—those they must and will fulfil; and so it is only by helping as it were in the fulfilment, not trying in vain to prevent it, that man can in anywise control or make use of these or any of the natural forces, forever in play and in mutual interdependence around him.

Let us apply this line of thought to a branch of engineering which has for some time attracted much attention, and nowhere so much as in our own small and densely-peopled island, where the health of masses of an ever-increasing population and their water supply press more and more upon our solicitude. What is the use of rivers, for what ends do they stand part of the great superficial machinery of our globe?

Brindley's well-known paradox—not far removed from nonsense, though so often repeated as an instance of the mental vigor of an untutored genius—will occur to most of our readers, but we may pass it by; the railway has long exploded the fallacy that the natural use of rivers was to feed navigable canals. Their chief uses or ends in relation to man and all subordinate creatures are, first, they are the main channels of discharge for rainfall; and, secondly, they are the natural sewers of all habitable land, receiving inevitably all fecal or solid and other matters carried by the rainfall into them, or all but that portion, probably not very large, which is directly soaked into and defecated in air or by the soil itself; thirdly, affording convenient and salutary sites upon their banks for cities and towns as presenting at once water in abundance and immediate discharge for the sewage, both being coupled with easy communication by water with the heart of the dry land and with the ocean; fourthly, affording a supply of food from fish, etc., which are, as regards one of their final causes, to be viewed as part of the machinery of purification of the waters in which they live. We pass by here the meteorological, political, and ethnographical ends or functions of rivers, though upon these, highly interesting as they are, volumes might be written. The causes that have fixed the sites of most great cities, especially the more ancient ones, elude any attempt to arrive at explanation. They have been too complex and various in sort, often too hap-hazard for disentanglement. Who can say why London is where it is and what it is? That the estuary of the Thames, the waters of which lend themselves to traffic by running in opposite directions twice in twenty-four hours, has had something to do with it is obvious. But the site once fixed by antecedent causes, and the tendency to accretion towards a great city once begun, we can see how much its destiny depends upon the relations between river and city. Whatever may have induced Pythæas and Euthymenes, the Greek founders of Marseilles, to have fixed its site where there was nothing but an insignificant brook, while the Rhone rolled its waters into the sea to the westward of it, we know that it has as a result been always an unhealthy city, though its growth has been great, and that at last an artificial river has had to be brought into its streets and turned into its foul and tideless harbor. On the other hand, Cologne—far older than the times of the Roman Empress, Agrippina, its reputed foundress—though fœtid enough in its narrow-streeted interior to have provoked Coleridge's gibe by its "well-defined and several stinks," is washed by the river Rhine, into which goes all its sewage and garbage; yet, such is the volume of the majestic stream that after it has passed this greatest of Rhine cities, and many other large places on its banks below that, yet at Dusseldorf, far below, and even lower down still, the river water is scarcely sensibly less pure than it is above Coblentz or Bingen.

It is obvious, then, that there is a certain balance between the size of cities and that of the rivers upon which they sit, which while preserved, nature herself relieves us of all the care as to the result, and the engineer will best let nature there alone; but if this balance be seriously disturbed by man, it may be inevitable that the engineer shall step in to restore the equilibrium so far as he can; and if the causes of disturbance be continued, and become sufficiently expanded, he will in the end prove powerless, and nature herself again steps in, and, slowly or not, restores the balance by disease or pestilence to check the undue city growth. Were London situated upon the St. Lawrence, or upon some other rapid river with a hundred times the volume of the Thames, we need not have troubled ourselves about main drainage, and commissions on river pollution would never have been heard of, though the river would contain the contents of the sewers, and above the town the water supply for 4,000,-

000 of people. But in London and the district round are the 4,000,000, and the Thames is but an insignificant stream in comparison; and cities and towns, villages and homesteads, stand thick upon its banks above London everywhere after the Thames has become a river. At length the engineer stepped in. What did he do? Some good and much harm. Sir Hugh Middleton, so far as he could, acted on right principles in bringing in a water supply from an extraneous source. Then came the epoch of water companies, each taking in its supply a little higher above the city. At last population along the river growing too much for them, a higher intake is deemed to be practically useless. Then comes filtration, etc., and finally commissions on river pollution. Then quackery of chemists and sanitarians, and sewage manure doctors. And at last it is seriously proposed to fly in nature's face, and declare by Act of Parliament that rivers are not, and therefore shall not be, the natural main sewers, with self-purifying apparatus of nature's own devising, but that chemical officials shall be set all over the land to watch and analyze the waters of every ditch, and pond, and drain, and, like Sancho Panza's physician, put their veto on any water getting into any river which may contain one part in a million of divers ingredients arbitrarily characterized by these chemists as detrimental to health.

An able exposure of the chemical quackery for the alleged prevention of the pollution of rivers—which was intended to have been introduced in the Public Health Bill of last session, but which was afterwards all struck out, and admitted by Mr. Stansfeld to be impracticable, who thus excused the Government at the expense of the results of its own River Commission—may be found in the "Chemical News" of July 25th, last (1873). Nevertheless, these same contradictory, absurd, and impracticable clauses were this session once more attempted to be made law by the Marquis of Salisbury, in the River Pollution Bill. It is full time that public attention be directed to these intended enactments, which will no doubt be revived either by the present or by a conservative Government, next session. If made law, the effect will be to place the whole country, and every home and manufactory on it, at the mercy of a swarm of paid chemical officials and officers of health, and to produce endless trouble and disputation before their utter absurdity shall have caused universal resistance and their repeal. The fact has forced itself into evidence that our rivers are too small, our climate too dry, and our population too dense along their banks for the rivers longer to remain in their natural condition and regimen as main sewers, and also for water supply. Main sewers they must forever continue to be—it is the law of nature that they must be so—and unless we can suspend such law, like "the standing orders," we shall have to let them remain the main sewers of our own as of every other land. We do not believe that there is one disinterested and competent engineer to be found who really believes that the sewerage of Maidenhead, Eton, Windsor, and Oxford, and possibly other towns on the Thames, can be disposed of by any artificial means consistent with the health and comfort of their inhabitants, and that the watery residue, poured sooner or later inevitably into the Thames, shall leave it pure and wholesome for animal consumption. Nature, in the soil, or vegetation, and the river itself, has marvellous power of defecation; all that man's work can do to supplement these is but a drop in the ocean.

But the mass of exuviæ poured ceaselessly into the Thames has already exceeded her power. The balancing point has been passed, though as yet not very heavily. Our London water is not very bad, though not as good even now, after filtration and subsidence, etc., as could be wished. But population grows and agglomerates without pause all along the Thames, and so it must become relatively and absolutely worse, and the grand apostle of "previous sewage contamination" cannot on his own premises—doubted or even laughed at as these are by the majority of chemists not interested in the pecuniary phases of the subject—but admit that to the end of the world this previous sewage contamination must find its way, unseen and unseeable, into the Thames.

Well, then, what in truth is the lesson that nature herself should teach us? It is this—the very opposite of the course we have adopted hitherto, and to that which it is proposed hereafter to enforce by Act of Parliament, whether accordant with nature's laws or not. We take our drinking water from the lower reaches of the river, after it has been polluted by sewage, navigation, and so forth. We take all sorts of

trouble then to unpollute the water, and to get it clear, at least, before it reaches our metropolis. At the same time we endeavor to prevent all the towns or cities above us from using their natural privilege of the river as their main sewer, though we treat it as such for ourselves. Nature herself tells us what we should have done, or should do even yet. Let the main river be the main sewer, as it cannot but be, and take our water supply, not from its polluted lower reaches, but from its uppermost *rigules* and collecting rivulets or gathering grounds. Make reservoirs upon these above the thick set centres of population, and so before it is polluted. Make these sufficiently numerous and of sufficient capacity, and bring down in aqueducts of pipes the pure supply, not only for London but for every other town above it. We believe that an ample supply may thus be secured from gathering grounds of suitable character, supplemented by the great chalk springs, for all our wants; but if not, then it will be time to ask the council of the nation to sanction our taking our water from some other river basin--the Severn, for example, or the Welsh or Cumberland lakes.

Sir William Fergusson was no doubt right in the main, when, lately, in his address as President of the Medical Congress in London, he quietly suggested that the machinery of agitation as to purity of water is one of the grand quackeries of the day; but we are convinced he would neither sanction dye stuffs nor chemical refuse being directly poured into rivers and streams; nor deny that water taken before nature has had time to complete her work of defecation is nauseous and, may be, poisonous. But he also probably sees that nothing that either chemist or engineer can do will enable a river, small in relation to its riparian dwellers, to remain a main sewer—as it must—and to be made a reservoir of pure and wholesome water for drinking at the same time. With a huge volume of water in the river, relatively to population, or with the latter thin and sparse, nature gives us both sewer and source in the one bed; and she is able, so to say, to nullify all injurious results of its existence as a sewer. But with small volumes and great population, we should follow the sound principles of most of the largest cities of the ancient world. Rome could not drink her muddy Tiber—she could even scarcely adapt to its periodically flooded stream any system of underground drainage. She was compelled thus into the right track for her hydraulic engineering. She brought her water from the upper streamlets of the Sabine hills and mountains around her, and carried it unpolluted and in copious volumes into the heart of her city. We had better follow in her steps, and upon a far broader scale, as indeed, Manchester, Sheffield, and many of our other great manufacturing towns have already done, and drop the Sisiphæan project of keeping all pollution—or what the chemists may please to deem such—out of our rivers.

STRUCTURAL AND ENGINEERING USES OF STEEL.*

From "Nature."

In the observations which I have to address to you I shall not attempt a general survey of a subject so vast and so varied as the manufactures of this country, nor shall I attempt to describe the many new and beautiful inventions and mechanical appliances which form a distinguishing feature of the age in which we live; but I shall endeavor to draw your attention to one of the new materials, namely modern steel—a material which, though of comparatively recent origin, has already become an important industry, and whose influence in the future seems destined to vie in importance with that resulting from the introduction of iron.

I have used the term "modern steel," because, although the great movement in simplifying and cheapening the process of producing steel is necessarily associated with the name of Mr. Bessemer, yet we have further important steps taken in a forward direction as to the production and treatment of steel by Dr. Siemens and Sir Joseph Whitworth and others, both in this country and abroad.

It is now seventeen years since Mr. Bessemer read a paper at the meeting of the British Association at Cheltenham,

* From the address of W. H. Barlow, F. R. S., President of the Mechanical Section of the British Association for the Advancement of Science.

which was entitled, "On the Manufacture of Iron and Steel without Fuel."

It is satisfactory to know that Mr. Bessemer has often expressed his firm conviction that had it not been for the publicity given to his invention through the paper which he read before the Mechanical Section of the British Association in 1856, and the great moral support afforded him by men of science whose attention was thereby directed to it, he believes that he would not have succeeded in overcoming the strong opposition with which his invention was met in other quarters.

About this time or perhaps a little later, a material was produced called "puddled steel," and about the same time the metal known as "homogeneous iron."

The movement which had begun in the production of cheap steel was further assisted and developed by the regenerative furnace of Dr. Siemens, by the introduction of the Siemens-Martin process of making steel, and further and most important progress is suggested by the recent process introduced by Dr. Siemens in making steel direct from the ore.

According to the returns published by the Jury of the International Exhibition of 1852, the total annual produce of steel in Great Britain at that time was 50,000 tons. At the present time there are more than 500,000 tons made by the Bessemer process alone, added to which Messrs. Siemens' works at Landore produce 200,000 tons, besides further quantities which are made by his process at Messrs. Vickers', Messrs. Cammells', the Dowlais, and other works.

I shall not, however, detain you by attempting to trace up the history and progress of steel, nor attempt to notice the various steps by which this branch of industry has been brought to its present important position. My object is to draw attention to this material as to its use and application for structural and engineering purposes.

The steel produced by the Bessemer process was at a very early stage employed in rails and wheel-tires. In both these applications the object sought was endurance to resist the effects of wear, and toughness to prevent fracture by blows. There does not exist at present sufficient information to determine accurately the relative values of steel and iron when used for these purposes. As used for wheel-tires, steel had to compete with iron of the highest quality, but it is nevertheless introduced on most of our railways. The iron used in rails was not of such a high quality, and the difference in duration shows a very marked advantage in the employment of steel, the duration of steel rails being variously estimated at from three to six times that of iron.

Steel is also extensively used for ships' plates, and by the War Department for lining the interior of the heaviest guns; while Sir Joseph Whitworth and Messrs. Krupp make guns entirely of steel, though for these purposes the metal is of different quality and differently treated, in order to withstand the enormous concussions to which it is subjected.

And, further, we have steel used in railway-axles, crank-axles for engines, in boilers, in piston rods, in carriage-springs, and for many other purposes.

But notwithstanding these various employments of steel, there has been, and there continues to be, a difficulty in applying it to engineering structures in this country.

The want of knowledge of the physical properties of steel having been the subject of remark at a discussion at the Institution of Civil Engineers in 1868, a committee, composed of Mr. Fowler, Mr. Scott Russell, Captain Galton, Mr. Berkley, and myself, undertook to conduct a series of experiments upon this subject.

The first were made for the Committee by Mr. Kirkaldy with his testing machine in London, and were chiefly directed to ascertain the relation which subsists between the resistance of tension, compression, torsion, and transverse strain.

In this series of experiments 29 bars, 15 ft. long, were used, each bar being cut into lengths and turned or planed into suitable forms for the respective tests, so that a portion of each bar was subjected to each of the above-mentioned tests.

The tensile resistance varied in the different qualities of steel from 28 to 48 tons per inch, and the experiments established conclusively that the relation subsisting between the several resistances of tension, compression, and transverse strain, is throughout practically the same as in wrought iron; that is to say, that a bar of steel whose tensile strength is 50 per cent. above that of wrought iron will exhibit about the same relative increase of resistance under the other tests.

They further showed that the limit of

elasticity in steel is, like that of wrought iron, rather more than half its ultimate resistance. The total elongation under tensile strain, and the evidences of malleability and toughness, will be referred to hereafter.

The second series recorded in the book published by the Committee gave the results of tempering steel in oil and water. They were made by the officers of the gun factory at the Royal Arsenal at Woolwich, and show a remarkable increase of strength obtained by this process. This property of steel is now fully recognized and made use of in the steel which forms the lining of the largest guns.

The third series of experiments was made by the Committee upon bars 14 ft. long, 1½ in. in diameter, with the skin upon the metal as it came from the rolls.

The object of these experiments was specially directed to ascertain the modulus of elasticity. They were made with the testing machine at H. M. Dockyard at Woolwich. which machine was placed at our disposal by the Admiralty. The bars were obtained, with some exceptions, in sets of six from each maker, three bars of each set being used in tension and three in compression.

Bars of iron of like dimensions were also tested in the same way, in order to obtain the relative effects in steel and iron. In these experiments 67 steel bars were tested whose tensile strength varied from 32 to 53 tons per inch, and 24 iron bars varying from 22 to 29 tons per inch.

The amount of the extensions and compressions were ascertained by direct measurement, verniers being for this purpose attached to the bar itself, 10 ft. apart, so that the readings gave the absolute extensions and compressions of this length of the bar.

These experiments, which were very accurately made, showed that the extension and compression of steel per ton per inch was a little less than wrought iron, that the extension and compression were very nearly equal to each other, and that the modulus of elasticity of steel may be taken at 30,000,000, which result agrees with the conclusions arrived at by American engineers on this subject.

This property of the metal is important in two respects. First, because inasmuch as the extension per ton per inch is practically equal to the compression, it follows that the neutral axis of a structure of steel, strained transversely, will be in the centre of gravity of its section, and that the proper proportion to give to the upper and lower flanges of a girder, when made of the same quality of steel throughout, will be the same as in wrought iron. Secondly, because the modulus of elasticity of steel is practically equal to that of wrought iron, aad the limit of elasticity is greater, it follows that in a girder of the same proportions as wrought iron, and strained with an equal proportion of its ultimate tensile strength, the deflection will be greater in the steel than in the iron girder, in the rate of the strength of the metals; so that if it is necessary to make a steel girder for a given span deflect under its load the same amount as an iron girder of the same span, the steel girder must be made of greater depth.

The fourth series of experiments were made by the Committee on riveted steel, and show clearly that the same rules which apply to the riveting of iron apply equally to steel; that is to say, that the total shearing area of the rivets must be the same, or rather must not be less, than the sectional area of the bar riveted.

We know from established mechanical laws that the limiting spans of structures vary directly as the strength of the material employed in their construction when the proportion of depth to span and all other circumstances remain the same. We know also that, taking an ordinary form of open wrought-iron detached girder (as, for example, when the depth is one-fourteenth of the span), the limiting span in iron, with a strain of 5 tons to the inch upon the metal, is about 600 ft.; and it follows that a steel girder of like proportions, capable of bearing 8 tons to the inch, would have theoretically a limiting span of 960 ft.

This theoretical limiting span of 960 ft. would, however, be reduced by some practical considerations connected with the minimum thickness of metal employed in certain parts, and it would, in effect, become about 900 ft. for a girder of the before mentioned construction and proportions.

The knowledge of the limiting span of a structure, as has been explained elsewhere, enables us to estimate very quickly, and with close approximation to the truth, the weight of girders required to carry given loads over given spans; and although the limiting spans vary with every form of structure, we can obtain an idea of the

effect of introducing steel by the relative weights of steel and iron required in girders of the kind above mentioned.

Assuming a load in addition to the weight of the girder of one ton to the foot, the relative weights under these conditions would be as follows:—

Span.	Weight of steel girder. tons.	Weight of iron girder. tons.
200	57	100
300	150	300
400	320	800

It is not alone in the relative weight or in the relative cost that the advantage of the stronger material is important, but with steel we shall be enabled to cross openings which are absolutely impracticable in iron.

It will naturally be asked why it is that steel is not used in these structures, if such manifest advantages would result from its employment.

The reason is twofold:—

1st. There is a want of confidence as to the reliability of steel in regard to its toughness and its power to resist fracture from sudden strain.

2d. Steel is produced of various qualities, and we do not possess the means, without elaborate testing, of knowing whether the article presented to us is of the required quality for structural purposes. A third reason, arising probably out of those before mentioned, is found in the fact that in the regulations of the Board of Trade relative to railway structures, although rules are given for the employment of cast-iron and wrought-iron, steel has not, up to the present time, been recognized or provided for.

Now, as regards the question of toughness and malleability, and referring again to Mr. Kirkaldy's experiments, it appears that in the tests of "Bessemer steel" 18 samples were tried under tensile strain, the length of the samples being in round numbers 50 in. and the diameter 1.382 in.; and that when these were subjected to ultimate strain, the elongation at the moment of fracture was in the most brittle example $2\frac{3}{4}$ in., but generally varied from $4\frac{1}{2}$ to $9\frac{1}{2}$ in.

In the experiments on transverse strain, in which the bars were nearly 2 in. sq. and only 20 in. between the points of support, all the "Bessemer steel" samples, except two, bent 6 in. without any crack. Again, in the experiments made by the Committee on bars 14 ft. long and $1\frac{1}{2}$ in. in diameter out of 20 bars of the milder quality of steel, 16 extended more than 8 in., and of these 10 extended more than 12 in.

The treatment by comparison is especially important where metal is required in large masses and of great ductility, because the larger the mass and the greater the ductility, the larger and more numerous are the air-cells, and the effect of the pressure is to completely close these cells and render the metal perfectly solid.

By this process mild steel can be made with a strength of 40 tons to the inch, having a degree of ductility equal to that of the best iron.

The more highly carbonized qualities show a decrease of ductility somewhat in the same ratio as the strength increases.

Without going into the numerous achievements of Sir Joseph Whitworth, resulting from the employment of steel, in connection with the extreme accuracy of workmanship produced at his works, or doing more than mention the flat-ended steel shot and shell which pass through iron plates when fired obliquely or penetrate ships' sides below the level of the water, I would call attention to those applications of steel which bear upon its strength and toughness.

In the first place, there are small arms made entirely of steel, of wonderful range and accuracy, capable of penetrating 34 half-inch planks, which is about three times the penetrating power of the Enfield rifle.

Secondly, there are the large guns, also entirely of steel, throwing projectiles from 250 lbs. to 310 lbs. in weight, and burning from 40 to 50 lbs. of powder at a charge, with which a range of nearly $6\frac{1}{2}$ miles is obtained.

In both these cases the degree of strength and toughness required in the metal is much greater than is necessary for engineering structures.

It is unnecessary to occupy more time in multiplying examples of the toughness of steel. It is well known to manufacturers, and must also be well known to many others here present, that steel of the strength of 33 or 36 tons per inch can be made, and is made in large quantities at moderate price, possessing all the toughness and malleability required in engineering structures.

I will proceed, therefore, to the second part of the subject—namely, the want of

means of knowing that a given sample of steel is of the quality suited for structural purposes.

With most other metals chemical analysis is in itself a complete and sufficient test of quality, but in steel it is not so. The toughness of steel may be altered by sudden cooling; and although the effect of this operation, and generally the effects of tempering, are greater when the quantity of carbon is considerable, yet it acts more or less in the mild qualities of steel; so that we cannot rely entirely on the aid of the chemist, but must fall back on mechanical tests. And in point of fact, seeing that the qualities required are mechanical, it is no more than reasonable that the test should be mechanical; for this includes not only the test of material but of workmanship.

Now there are two descriptions of mechanical testing, which may be distinguished as destructive and non-destructive—the one being beyond and the other within the elastic limit of the material. The destructive test is that usually applied to a part of an article manufactured, as, for example, a piece cut off a boiler plate and tested by absolute rupture, or by bending or otherwise, whereby the strength and quality of the material in the plate is known.

The non-destructive test is that usually applied to the finished work, as in the test of a boiler by hydraulic pressure, or the testing of a gun by the proof-charge. The strain in this case is made greater than that which will arise in the daily use of the article, but is not so greatly in excess as to be beyond the elastic limit of the material.

As regards engineering structures, this second test is easy of application; but it affords no sufficient criterion that the metal possesses that degree of toughness necessary to resist the action of sudden strains.

It may be said that engineers may ascertain for themselves, by inspection and testing at the works, that they are being supplied with the material that they require; but assuming that the tests and mode of testing were in all respects satisfactory to them, and that the metal supplied was of the right quality, we have still to comply with the conditions of the Act for the Regulation of Railways, and we must satisfy the Government Inspector.

It is not to be supposed that he can attend all the required tests at the works; and the question remains, how is the Inspecting Officer of the Board of Trade to be enabled to distinguish the quality of metal in a finished bridge, when he is called upon to give a certificate that it is safe for public traffic?

If we could adduce clear and distinct evidence that the metal used for a bridge was of a quality which would bear 8 tons to the inch with as much safety as common iron can bear 5 tons, there can be no reasonable doubt that the Board of Trade would make suitable provision in its regulations for the employment of such material.

The difficulty lies in the want of something whereby the quality of the metal may be known and relied upon with confidence by others besides those who made the article.

In gold and silver this is accomplished by the stamp put upon them, in guns and small arms we have the proof-mark, but in iron and steel we have nothing whereby the one quality of metal can be distinguished from another; and until some sufficient means be devised for this purpose, it is difficult to see how we are to escape from the position in which we are now placed—namely, that while we possess a material by which we can increase considerably the spans and diminish the weight and cost of engineering works, we are restricted to make designs and construct our works by a rule made for wrought iron, and adapted to the lowest quality of that material.

As the rule made by the Board of Trade in respect of wrought-iron railway structures may not be generally known, I here give it:

"In a wrought-iron bridge the greatest load which can be brought upon it, added to the weight of the superstructure, should not produce a greater strain on any part of material than 5 tons per inch."

It will be observed that this 5 tons per inch is the governing element, irrespective entirely of the quality of metal used; and it is obvious that a rule so framed must act as a discouragement to any endeavor to improve the quality of metal, while it tends to induce the employment of the cheapest and most inferior descriptions which can be made under the name of wrought-iron.

In endeavoring to seek an amendment of the rules, which will permit of the employment of steel or other metal of higher strength than 5 tons to the inch, I feel bound to say that I do not consider that the Board of Trade is alone responsible for the position in which the question now stands; and as regards the Government

Inspecting Officers, I can only say that in the numerous transactions I have had with them, and although differences of opinion have occasionally arisen, yet, considering the responsibility which rests upon them, I have found them anxious to afford all reasonable facilities so far as their instructions permitted.

The first step to be taken is to put our testing on a systematic and satisfactory basis.

The second is to establish some means whereby metal which has been tested can have its quality indicated upon it in such manner that it can be practically relied upon.

The experiments before referred to establish, sufficiently for all practical purposes, that the relation or proportion between the resistances to tension, compression, torsion, and transverse strain, is about the same in steel as in wrought iron.

The testing required is therefore reduced to that necessary for ascertaining two properties, namely the strength and the toughness or ductility.

The strength may be readily ascertained, and no difficulty arises on that head.

The whole question turns upon the test for ductility, or the resistance to fracture by blows or sudden strain; and it must be admitted that the tests employed for this purpose are not framed on any regular or satisfactory basis.

Without, however, attempting to say what description of test may be found the best for ascertaining the property of ductility, it may be observed that what is required for this test is a definite basis to act upon, and that the samples should be so made as to render the test cheap, expeditious, and easy of application.

The next requirement is, that when a piece of metal has been tested, and its qualities of strength and toughness ascertained, there should be some means of denoting its quality in an authentic manner.

To a certain extent this is already done in iron by the mark of the maker; but something more than this is necessary to fulfil the required conditions in steel.

What is termed steel, is iron with a small proportion of carbon in it. These two ingredients are necessary to constitute steel; and there may or may not be present in very small quantities graphite, silicon, manganese, sulphur, and phosphorus.

In connection with the experiments made by the Committee, fourteen of the samples were tested by Mr. E. Richards, of the Barrow Steel Works, five of which were kindly repeated by Dr. Odling.

Although there are some discrepancies in the results which we cannnot account for, yet some of the characteristics are brought out clearly.

It appears that manganese may be present to the extent of $\frac{4}{10}$ths per cent. without injury either to the strength or ductility, but sulphur and phosphorus, except in extremely small quantities, are fatal to ductility.

In the samples tried by the Committee and Mr. Kirkaldy, the quantity of carbon varied from $\frac{1}{3}$ per cent. to nearly 1 per cent.; yet with this small variation in the carbon the strength ranged from 33 tons to nearly 53 tons per in.; and the ductility, represented by the ratio which the fractured area bore to the original section of the bar, varied from $\frac{5}{10}$ths in the tough qualities, until in the harder samples there was no diminution perceptible.

All these materials are called steel, and have the same external appearance; but possessing, as they do, such a range of strength and such a variation in ductility, it becomes absolutely essential that there should be some classification or means of knowing the respective qualities among them.

The want of such classification casts an air of uncertainty over the whole question of steel, and impedes its application. To this want of knowledge is to be ascribed the circumstance that many professional men regard the material as altogether unreliable; while large consumers of steel, in consequence of the uncertainty of the quality they buy in the market, seek to establish works on their own premises and make their own steel.

I ought, I know, to apologize for detaining you so long on this one question of steel, but I consider that the difficulties under which it is placed are affecting interests of considerable importance.

Not only is a large and useful field for the employment of steel practically closed, but the progress of improvement in engineering structures is impeded both in this country and in other parts of the world where English engineers are engaged.

For, in consequence of the impediments to its employment in England, very few

English engineers turn their attention to the use of steel. They are accustomed to make their designs for iron, and when engaged in works abroad where the Board of Trade rules do not apply, they continue for the most part to send out the old-fashioned ponderous girders of common iron, in cases where the freight and difficulties of carriage make it extremely desirable that structures of less weight and more easy transport should be employed.

In conclusion, and while thanking you for the patience with which you have heard me on this subject, I would observe that we possess in steel a material which has been proved, by the numerous uses to which it is applied, to be of great capability and value; we know that it is used for structural purposes in other countries, as, for example, in the Illinois and St. Louis Bridge in America, a bridge of three arches, each 500 ft. span; yet in this country, where "modern steel" has originated and has been brought to its present state of perfection, we are obstructed by some deficiency in our arrangements, and by the absence of suitable regulations by the Board of Trade, from making use of it in engineering works.

And I have considered it right to draw your attention to the position in which this question stands, well knowing that I could not address anybody of gentlemen more capable of improving and systematizing our methods of testing, or better able to devise effectual means for removing the impediments to the use of steel, than are to be found in the scientific and practical men who form the Mechanical Section of the British Association.

TUNNEL LOCOMOTIVES.

From "The Engineer."

Notwithstanding the expenditure of a considerable sum in the improvement of the ventilation of the Metropolitan Railway, the air in the tunnels is still very far from being in a satisfactory condition. When the line was first opened it was expected that by running a train each way every twenty minutes the demands of the public would be fully satisfied; and we believe that had any one at the time the construction of the railway was first proposed suggested the possibility of a train every five minutes being required to conduct the traffic satisfactorily, he would have exposed himself to severe ridicule. The line has now been opened ten years, and the trains run at about two minute intervals during the busy portions of the day. From the first, difficulties were anticipated as regards ventilation; and before the line was opened a condensing locomotive was constructed with air pumps and a jet condenser. We are not aware that this engine ever ran more than a few experimental trips, after which it went to the scrap heap. The line was first worked by broad-gauge tank engines with 6 wheels, 4 coupled, and outside cylinders, with the appearance of which no doubt many of our readers are familiar. They were fitted with tanks under the boilers, into which the waste steam was turned and condensed, the heated water being discharged at Farringdon street and Paddington. The length of the run was, roughly stated, about 3 miles. This arrangement, on the whole, disposed of the steam satisfactorily, and so long as not more than six trains per hour traversed any given section of the line, there was not much to complain of as regarded ventilation. By degrees, however, the number of trains increased, and complaints began to be heard about the state of the atmosphere. Then came the dispute between the Metropolitan and the Great Western Companies. The latter refused to work the line, and as the Metropolitan Company had no locomotives ready, the Great Northern Company conducted the traffic with some of their ordinary goods engines, the waste steam being led into the tender by a flexible pipe. These tenders held more water than the tanks of their predecessors, and the steam gave no trouble whatever, but the fire-boxes were comparatively small and the blast was often required to urge the fire. As a result the air became more impregnated than ever with sulphuretted hydrogen, sulphurous acid, and carbonic acid gas. The public complained lustily, but Mr. Fowler designed the engines and rolling stock now in use, and the public were assured that once these engines were put on there would be no more trouble. Immense fire-boxes were used to avoid the necessity for a draught—

as the world was told—and the steam was got rid of in the side tanks. If is probable that if the number of trains had remained small, these hopeful anticipations would have been to a great extent fulfilled, but the traffic increased enormously, reaching at last to 1,000 trains in twenty-four hours—one hour at night being reserved for repairs—or more than 43 per hour. Nor does this number represent the whole traffic now run through Farringdon street and up to King's Cross and Paddington, for it does not include the trains run by the Great Northern, Great Western, and Midland Companies. Nor was the increased number of trains the only difficulty with which the Metropolitan Company have had to deal; in addition, the length of each run has been augmented. Instead of working with the dampers down, they are worked full open, and catching the air as the train runs, there is actually in practice so rapid a combustion effected, that the engines make steam during the whole run. The consumption is about 32 lbs. per train mile; and as the engines seldom use their blowers while standing in stations, it is obvious that almost the whole of this is consumed when running, that is to say, in the tunnels. The water carried is also insufficient to condense all the steam. It becomes nearly boiling hot at the end of the run, and there is therefore a very considerable escape of steam in the tunnels near each terminus. On the Metropolitan District line there is apparently some difficulty about getting an adequate supply of water, and the engines run from the Mansion House to West Brompton and back without changing the water in the tanks. The consequence is that steam escapes in clouds from the engines running into the Mansion House Station, and one serious accident has occurred because it was impossible for the driver to see the signals. For some time past this difficulty has claimed all Mr. Speck's attention, and we know that he has been experimenting with a view to get rid of it. For example, he has led the waste steam through the furnace, in order to superheat the exhaust and render it invisible. The plan has answered tolerably well in all respects but one: the consumption of fuel was, from some cause not very easy to explain, increased by nearly 50 per cent. It is not probable that the use of locomotives in long tunnels will be confined to London. To say nothing of the Mont Cenis and St. Gothard tunnels, an underground line is contemplated for New York; another has been spoken of for Paris; the use of locomotives in coal pits has been attempted, and, all things considered, there is reason to believe that tunnel locomotives are likely to play a more important part than ever. Under these circumstances it is worth while to consider if any, and what, modifications are required in their structure to make them more suitable for their underground life.

The first thing to be done is to get rid almost, if not altogether, of the escape of the products of combustion in a tunnel; the second thing is to get rid of the escape of visible steam. We believe that it is possible to effect both objects, but it can only be done by introducing very important modifications in the existing type of engine. If it can be shown that change is necessary, and will be attended with advantage, then no predilection for existing methods of construction should be allowed to stand in the way. The disposal of the steam difficulty will, in our opinion, be best effected by first condensing as much as possible in tanks as now, and then leading what escapes from the tanks when the water has reached the boiling point into a superheater, by which the steam will be rendered invisible. There are other methods by which the steam may be disposed of to which we may return, but for the present we shall confine our attention to the disposal of the products of combustion. To dispense absolutely with the presence of carbonic acid gas and sulphurous acid in a tunnel such as the Metropolitan Railway traverses, is, we may state at the outset, quite impossible if engine furnaces are to be used. The utmost that can be hoped is the reduction to a minimum of the discharge of noxious gases from the engine; and it must be well borne in mind that if these gases are once produced in quantity there is no effectual way of getting rid of them. No practical form of ventilation will clear the tunnel when trains follow close on each other's heels. Various schemes have been proposed by chemists for neutralizing the acids—for example, the use of boxes containing quick-lime through which the air supplied to the carriages would be drawn; but to most schemes of this kind there are some objections, especially on the score of expense. The true remedy lies in not making these gases while in the tunnel in any quantity, and

this is one reason why the weight of the rolling stock should be kept as small as possible. Thus, for example, as the little engines for working the Metropolitan traffic of the Brighton line only burn about two-thirds as much coal per train mile as Mr. Fowler's engines on the Metropolitan, it follows that the first-mentioned engines would only discharge two-thirds of the deleterious gases delivered from the chimneys of the latter. This would be equivalent to an immense increase in the ventilation of the line. The theory on which Mr. Fowler started is no doubt correct. No steam should be made in the tunnels, and all the dampers should be kept shut. The delivery of gas from the furnace would, under these conditions, be very small indeed. In practice, however, Mr. Fowler's theory cannot be applied. It may be applied, however, in perfection, provided certain modifications are adopted in the construction of the engine.

In order to dispense with the aid of the furnace in running, it is essential that the engine shall carry so much water, heated to such a temperature as will suffice for effecting those portions of the run which are made in tunnels, and sufficient time must elapse between any two consecutive runs to enable the engine to recover the pressure lost while in motion. In a word, the water in the boiler must be used as a receptacle in which to store up heat for each run.

Two methods of carrying this scheme out in practice suggest themselves: either the pressure carried in the boiler, to begin with, must be so great that in falling to the working pressure sufficient sensible heat will be available for conversion into latent heat, or enough water must be carried to supply all the steam required, although the pressure only falls a few pounds. Under the first system the boiler pressure would be, say 400 lbs. on the square inch; but a reducing valve would be provided by which steam of, say, more than 120 lbs. would not reach the cylinder. To begin with, the fire would be urged by a powerful blower while the engine was standing; as soon as the requisite pressure was reached, the dampers would all be closed, the blower taken off, and the engine would then make its run, using up the heat stored in the water in the boiler. The pressure would probably fall to 100 lbs. by the time the run was complete. The blower would then again be put on and the damper opened; at this time also the boiler would be supplied with water. The pressure would once more be raised to the proper point, and the engine would be ready for another run.

If, instead of using a very high pressure, the quantity of water carried were augmented, the action and method of working would be just the same. As to the pressures and quantity of water required for any particular duty, we shall say more presently. For the moment, we have to consider—granting that every other condition is favorable—whether it would be practicable to work engines thus—we mean practicable in the sense of convenience and cost. It is obvious, for example, that if it required an hour to raise steam to the required pressure, the scheme would fail, because, instead of one engine to each train, three or more would be required to conduct the traffic on the Metropolitan Railway. We believe we shall not be far wrong if we say that, provided not more than ten minutes were required to raise steam, the scheme could be applied without much difficulty. Admitting that this obstacle is got over, say by providing a few additional engines, we have next to consider how steam is to be raised. We have spoken of a fire-box and a blower, but we believe that infinitely the better plan would be to arrange at each terminus a modification of the Siemens furnace. Each engine would be brought over a suitable gas burner, if we may use the word, and steam would be got up with lightning speed. There would be no delay to get the fire up. It would only be necessary to bring each engine over the gas burner on a siding, turn on the flame, and run up the pressure. Engine would succeed engine with perfect regularity, and the production of steam would be really continuous. In a word, the engines would take in heat as they now take in water. And here we must call attention to one most important feature of the scheme. Not only would the tunnels be kept perfectly clear of gas, but instead of using most expensive coal, the companies could at once resort to the use of small cheap slack. Any kind of coal, indeed, would give good results in the Siemens gas-producer; the savings from this cause would soon tell sensibly on dividends.

It is not difficult to determine the time which would be required to get up steam.

Let us suppose that a run from Moorgate street to Paddington now occupies half an hour. Then it is obvious that all the time required to generate the steam used on the run is half an hour. It is admitted, however, that the engines do not make nearly as much steam as they would make with the blast on. Therefore, if the fire were properly urged, it is likely that all the pressure needed could be generated in fifteen minutes; and it is not too much to assume that a Siemens gas flame used without much regard to economy—which would be unnecessary because of the small cost of the fuel—would get up the steam in ten minutes or even less. That the sudden alterations of temperature to which the fire-box would be exposed would prove injurious, is very true, but the difficulty admits of being got over.

Some years ago a proposal somewhat similar to that which we have just made was put before the world. An important difference exists, however. We propose to heat the water in the engine boiler by the aid of a Siemens furnace. The original scheme was to heat water to a very high temperature in stationary boilers at each end of the line and then to fill up receivers answering to the existing boilers on the engines with this highly heated water. There are serious practical difficulties in the way of the latter scheme which do not apply to ours. We must reserve for another article a numerical statement of the data on which our reasoning is based.

MOLECULES.*

From "Nature."

An atom is a body which cannot be cut in two. A molecule is the smallest possible portion of a particular substance. No one has ever seen or handled a single molecule. Molecular science, therefore, is one of those branches of study which deal with things invisible and imperceptible by our senses, and which cannot be subjected to direct experiment.

The mind of man has perplexed itself with many hard questions. Is space infinite, and if so in what sense? Is the material world infinite in extent, and are all places within that extent equally full of matter? Do atoms exist, or is matter infinitely divisible?

The discussion of questions of this kind has been going on ever since men began to reason, and to each of us, as soon as we obtain the use of our faculties, the same old questions arise as fresh as ever. They form as essential a part of the science of the nineteenth century of our era, as of that of the fifth century before it.

We do not know much about the science organization of Thrace twenty-two centuries ago, or of the machinery then employed for diffusing an interest in physical research. There were men, however, in those days, who devoted their lives to the pursuit of knowledge with an ardor worthy of the most distinguished members of the British Association; and the lectures in which Democritus explained the atomic theory to his fellow-citizens of Abdera realized, not in golden opinions only, but in golden talents, a sum hardly equalled even in America.

To another very eminent philosopher, Anaxagoras, best known to the world as the teacher of Socrates, we are indebted for the most important service to the atomic theory, which, after its statement by Democritus, remained to be done. Anaxagoras, in fact, stated a theory which so exactly contradicts the atomic theory of Democritus that the truth or falsehood of the one theory implies the falsehood or truth of the other. The question of the existence or non-existence of atoms cannot be presented to us this evening with greater clearness than in the alternative theories of these two philosophers.

Take any portion of matter, say a drop of water, and observe its properties. Like every other portion of matter we have ever seen, it is divisible. Divide it in two, each portion appears to retain all the properties of the original drop, and, among others, that of being divisible. The parts are similar to the whole in every respect except in absolute size.

Now go on repeating the process of division till the separate portions of water are so small that we can no longer perceive or handle them. Still we have no doubt that

* Lecture delivered before the British Association at Bradford, by Prof. Clerk-Maxwell, F. R. S.

the subdivision might be carried further, if our senses were more acute and our instruments more delicate. Thus far all are agreed, but now the question arises, can this subdivision be repeated forever?

According to Democritus and the atomic school, we must answer in the negative. After a certain number of subdivisions, the drop would be divided into a number of parts, each of which is incapable of further subdivision. We should thus, in imagination, arrive at the atom, which, as its name literally signifies, cannot be cut in two. This is the atomic doctrine of Democritus, Epicarus, and Lucretius, and, I may add, of your lecturer.

According to Anaxagoras, on the other hand, the parts into which the drop is divided, are in all respects similar to the whole drop, the mere size of a body connting for nothing as regards the nature of its substance. Hence, if the whole drop is divisible, so are its parts down to the minutest subdivisions, and that without end.

The essence of the doctrine of Anaxagoras is that the parts of a body are in all respects similar to the whole. It was therefore called the doctrine of Homoiomereia. Anaxagoras did not of course assert this of the parts of organized bodies such as men and animals, but he maintained that those inorganic substances which appear to us homogeneous are really so, and that the universal experience of mankind testifies that every material body, without exception, is divisible.

The doctrine of atoms and that of homogeneity are thus in direct contradiction.

But we must now go on to molecules. Molecule is a modern word. It does not occur in Johnson's Dictionary. The ideas it embodies are those belonging to modern chemistry.

A drop of water, to return to our former example, may be divided into a certain number, and no more, of portions similar to each other. Each of these the modern chemist calls a molecule of water. But it is by no means an atom, for it contains two different substances, oxygen and hydrogen, and by a certain process the molecule may be actually divided into two parts, one consisting of oxygen and the other of hydrogen. According to the received doctrine, in each molecule of water there are two molecules of hydrogen and one of oxygen. Whether these are or are not ultimate atoms I shall not attempt to decide.

We now see what a molecule is, as distinguished from an atom.

A molecule of a substance is a small body such that if, on the one hand, a number of similar molecules were assembled together they would form a mass of that substance, while on the other hand, if any portion of this molecule were removed, it would no longer be able, along with an assemblage of other molecules similarly treated, to make up a mass of the original substance.

Every substance, simple or compound, has its own molecule. If this molecule be divided, its parts are molecules of a different substance or substances from that of which the whole is a molecule. An atom, if there is such a thing, must be a molecule of an elementary substance. Since, therefore, every molecule is not an atom, but every atom is a molecule, I shall use the word molecule as the more general term.

I have no intention of taking up your time by expounding the doctrines of modern chemistry with respect to the molecules of different substances. It is not the special but the universal interest of molecular science which encourages me to address you. It is not because we happen to be chemists or physicists or specialists of any kind that we are attracted towards this centre of all material existence, but because we all belong to a race endowed with faculties which urge us on to search deep and ever deeper into the nature of things.

We find that now, as in the days of the earliest physical speculations, all physical researches appear to converge towards the same point, and every inquirer, as he looks forward into the dim region towards which the path of discovery is leading him, sees, each according to his sight, the vision of the same quest.

One may see the atom as a material point, invested and surrounded by potential forces. Another sees no garment of force, but only the bare and utter hardness of mere impenetrability.

But though many a speculator, as he has seen the vision recede before him into the innermost sanctuary of the inconceivably little, has had to confess that the quest was not for him, and though philosophers in every age have been exhorting each other to direct their minds to some more useful and attainable aim, each generation, from the earliest dawn of science to the present time, has contributed a due proportion of

its ablest intellects to the quest of the ultimate atom.

Our business this evening is to describe some researches in molecular science, and in particular to place before you any definite information which has been obtained respecting the molecules themselves. The old atomic theory, as described by Lucretius and revived in modern times, asserts that the molecules of all bodies are in motion, even when the body itself appears to be at rest. These motions of molecules are in the case of solid bodies confined within so narrow a range that even with our best microscopes we cannot detect that they alter their places at all. In liquids and gases, however, the molecules are not confined within any definite limits, but work their way through the whole mass, even when that mass is not disturbed by any visible motion.

This process of diffusion, as it is called, which goes on in gases and liquids and even in some solids, can be subjected to experiment, and forms one of the most convincing proofs of the motion of molecules.

Now the recent progress of molecular science began with the study of the mechanical effect of the impact of these moving molecules when they strike against any solid body. Of course these flying molecules must beat against whatever is placed among them, and the constant succession of these strokes is, according to our theory, the sole cause of what is called the pressure of air and other gases.

This appears to have been first suspected by Daniel Bernoulli, but he had not the means which we now have of verifying the theory. The same theory was afterwards brought forward independently by Lesage, of Geneva, who, however, devoted most of his labor to the explanation of gravitation by the impact of atoms. Then Herapath, in his "Mathematical Physics," published in 1847, made a much more extensive application of the theory to gases, and Dr. Joule, whose absence from our meeting we must all regret, calculated the actual velocity of the molecules of hydrogen.

The further development of the theory is generally supposed to have been begun with a paper by Krönig, which does not, however, so far as I can see, contain any improvement on what had gone before. It seems, however, to have drawn the attention of Prof. Clausius to the subject, and to him we owe a very large part of what has been since accomplished.

We all know that air or any other gas placed in a vessel presses against the sides of the vessel, and against the surface of anybody placed within it. On the kinetic theory this pressure is entirely due to the molecules striking against these surfaces, and thereby communicating to them a series of impulses which follow each other in such rapid succession that they produce an effect which cannot be distinguished from that of a continuous pressure.

If the velocity of the molecules is given, and the number varied, then since each molecule, on an average, strikes the side of the vessel the same number of times, and with an impulse of the same magnitude, each will contribute an equal share to the whole pressure. The pressure in a vessel of given size is therefore proportional to the number of molecules in it, that is, to the quantity of gas in it.

This is the complete dynamical explanation of the fact discovered by Robert Boyle, that the pressure of air is proportional to its density. It shows also that of different portions of gas forced into a vessel, each produces its own part of the pressure independently of the rest, and this whether these portions be of the same gas or not.

Let us next suppose that the velocity of the molecules is increased. Each molecule will now strike the sides of the vessel a greater number of times in a second, but besides this, the impulse of each blow will be increased in the same proportion, so that the part of the pressure due to each molecule will vary as the *square* of the velocity. Now the increase of the square of velocity corresponds, in our theory, to a rise of temperature, and in this way we can explain the effect of warming the gas, and also the law discovered by Charles that the proportional expansion of all gases between given temperatures is the same.

The dynamical theory also tells us what will happen if molecules of different masses are allowed to knock about together. The greater masses will go slower than the smaller ones, so that, on an average, every molecule, great or small, will have the same energy of motion.

The proof of this dynamical theorem, in which I claim the priority, has recently been greatly developed and improved by

Dr. Ludwig Boltzmann. The most important consequence which flows from it is, that a cubic centimetre of every gas at standard temperature and pressure contains the same number of molecules. This is the dynamical explanation of Gay Lussac's law of the equivalent volumes of gases. But we must now descend to particulars, and calculate the actual velocity of a molecule of hydrogen.

A cubic centimetre of hydrogen, at the temperature of melting ice and at a pressure of one atmosphere, weighs 0.00008954 grammes We have to find at what rate this small mass must move (whether altogether or in separate molecules makes no difference) so as to produce the observed pressure on the sides of the cubic centimetre. This is the calculation which was first made by Dr. Joule, and the result is 1,859 metres per second. This is what we are accustomed to call a great velocity. It is greater than any velocity obtained in artillery practice. The velocity of other gases is less, as you will see by the table, but in all cases it is very great as compared with that of bullets.

We have now to conceive the molecules of the air in this hall flying about in all directions, at a rate of about seventeen miles in a minute.

If all these molecules were flying in the same direction, they would constitute a wind blowing at the rate of seventeen miles a minute, and the only wind which approaches this velocity is that which proceeds from the mouth of a cannon. How, then, are you and I able to stand here? Only because the molecules happen to be flying in different directions, so that those which strike against our backs enable us to support the storm which is beating against our faces. Indeed, if this molecular bombardment were to cease, even for an instant, our veins would swell, our breath would leave us, and we should, literally, expire. But it is not only against us or against the walls of the room that the molecules are striking. Consider the immense number of them, and the fact that they are flying in every possible direction, and you will see that they cannot avoid striking each other. Every time that two molecules come into collision, the paths of both are changed, and they go off in new directions. Thus each molecule is continually getting its course altered, so that in spite of its great velocity it may be a long time before it reaches any great distance from the point at which it set out.

I have here a bottle containing ammonia. Ammonia is a gas which you can recognize by its smell. Its molecules have a velocity of 600 metres per second, so that if their course had not been interrupted by striking against the molecules of air in the hall, every one in the most distant gallery would have smelt ammonia before I was able to pronounce the name of the gas. But instead of this, each molecule of ammonia is so jostled about by the molecules of air, that it is sometimes going one way and sometimes another. It is like a hair which is always doubling, and though it goes a great pace, it makes very little progress. Nevertheless, the smell of ammonia is now beginning to be perceptible at some distance from the bottle. The gas does diffuse itself through the air, though the process is a slow one, and if we could close up every opening of this hall so as to make it airtight, and leave everything to itself for some weeks, the ammonia would become uniformly mixed through every part of the air in the hall.

This property of gases, that they diffuse through each other, was first remarked by Priestley. Dalton showed that it takes place quite independently of any chemical action between the inter-diffusing gases. Graham, whose researches were especially directed towards those phenomena which seem to throw light on molecular motions, made a careful study of diffusion, and obtained the first results from which the rate of diffusion can be calculated.

Still more recently the rates of diffusion of gases into each other have been measured with great precision by Prof. Loschmidt of Vienna.

He placed the two gases in two similar vertical tubes, the lighter gas being placed above the heavier, so as to avoid the formation of currents. He then opened a sliding valve, so as to make the two tubes into one, and after leaving the gases to themselves for an hour or so, he shut the valve, and determined how much of each gas had diffused into the other.

As most gases are invisible, I shall exhibit gaseous diffusion to you by means of two gases, ammonia and hydrochloric acid, which, when they meet, form a solid product. The ammonia, being the lighter gas, is placed above the hydrochloric acid, with a stratum of air between, but you will soon

see that the gases can diffuse through this stratum of air, and produce a cloud of white smoke when they meet. During the whole of this process no currents or any other visible motion can be detected. Every part of the vessel appears as calm as a jar of undisturbed air.

But, according to our theory, the same kind of motion is going on in calm air as in the inter-diffusing gases, the only difference being that we can trace the molecules from one place to another more easily when they are of a different nature from those through which they are diffusing.

If we wish to form a mental representation of what is going on among the molecules in calm air, we cannot do better than observe a swarm of bees, when every individual bee is flying furiously, first in one direction, and then in another, while the swarm, as a whole, either remains at rest, or sails slowly through the air.

In certain seasons, swarms of bees are apt to fly off to a great distance, and the owners, in order to identify their property when they find them on other people's ground, sometimes throw handfuls of flour at the swarm. Now let us suppose that the flour thrown at the flying swarm has whitened those bees only which happened to be in the lower half of the swarm, leaving those in the upper half free from flour.

If the bees still go on flying hither and thither in an irregular manner, the floury bees will be found in continually increasing proportions in the upper part of the swarm, till they have become equally diffused through every part of it. But the reason of this diffusion is not because the bees were marked with flour, but because they are flying about. The only effect of the marking is to enable us to identify certain bees.

We have no means of marking a select number of molecules of air, so as to trace them after they have become diffused among others, but we may communicate to them some property by which we may obtain evidence of their diffusion.

For instance, if a horizontal stratum of air is moving horizontally, molecules diffusing out of this stratum into those above and below will carry their horizontal motion with them, and so tend to communicate motion to the neighboring strata, while molecules diffusing out of the neighboring strata into the moving one will tend to bring it to rest. The action between the strata is somewhat like that of two rough surfaces, one of which slides over the other, rubbing on it. Friction is the name given to this action between solid bodies; in the case of fluids it is called internal friction or viscosity.

It is in fact only another kind of diffusion —a lateral diffusion of momentum, and its amount can be calculated from data derived from observations of the first kind of diffusion, that of matter. The comparative values of the viscosity of different gases were determined by Graham in his researches on the transpiration of gases through long narrow tubes, and their absolute values have been deduced from experiments on the oscillation of discs by Oscar Meyer and myself.

Another way of tracing the diffusion of molecules through calm air is to heat the upper stratum of the air in a vessel, and so observe the rate at which this heat is communicated to the lower strata. This, in fact, is a third kind of diffusion—that of energy, and the rate at which it must take place was calculated from data derived from experiments on viscosity before any direct experiments on the conduction of heat had been made. Prof. Stefan, of Vienna, has recently, by a very delicate method, succeeded in determining the conductivity of air, and he finds it, as he tells us, in striking agreement with the value predicted by the theory.

All these three kinds of diffusion—the diffusion of matter, of momentum, and of energy—are carried on by the motion of the molecules. The greater the velocity of the molecules and the farther they travel before their paths are altered by collision with other molecules, the more rapid will be the diffusion. Now we know already the velocity of the molecules, and therefore by experiments on diffusion we can determine how far, on an average, a molecule travels without striking another. Prof. Clausius, of Bonn, who first gave us precise ideas about the motion of agitation of molecules, calls this distance the mean path of a molecule. I have calculated from Prof. Loschmidt's diffusion experiments, the mean path of the molecules of four well-known gases. The average distance travelled by a molecule between one collision and another is given in the table. It is a very small distance, quite imperceptible to us even with our best microscopes. Roughly speaking, it is about the tenth part of the length of a

wave of light, which you know is a very small quantity. Of course the time spent on so short a path by such swift molecules must be very small. I have calculated the number of collisions which each must undergo in a second. They are given in the table and are reckoned by thousands of millions. No wonder that the travelling power of the swiftest molecule is but small, when its course is completely changed thousands of millions in a second.

The three kinds of diffusion also take place in liquids, but the relation between the rates at which they take place is not so simple as in the case of gases. The dynamical theory of liquids is not so well understood as that of gases, but the principal difference between a gas and a liquid seems to be that in a gas each molecule spends the greater part of its time in describing its free path, and is for a very small portion of its time engaged in encounters with other molecules, whereas in a liquid the molecule has hardly any free path, and is always in a state of close encounter with other molecules.

Hence in a liquid the diffusion of motion from one molecule to another takes place much more rapidly than the diffusion of the molecules themselves, for the same reason that it is more expeditious in a dense crowd to pass on a letter from hand to hand than to give it to a special messenger to work his way through the crowd. I have here a jar, the lower part of which contains a solution of copper sulphate, while the upper part contains pure water. It has been standing here since Friday, and you see how little progress the blue liquid has made in diffusing itself through the water above. The rate of diffusion of a solution of sugar has been carefully observed by Voit. Comparing his results with those of Loschmidt on gases, we find that about as much diffusion takes place in a second in gases as requires a day in liquids.

The rate of diffusion of momentum is also slower in liquids than in gases, but by no means in the same proportion. The same amount of motion takes about ten times as long to subside in water as in air, as you will see by what takes place when I stir these two jars, one containing water and the other air. There is still less difference between the rates at which a rise of temperature is propagated through a liquid and through a gas.

In solids the molecules are still in motion, but their motions are confined within very narrow limits. Hence the diffusion of matter does not take place in solid bodies, though that of motion and heat takes place very freely. Nevertheless, certain liquids can diffuse through colloid solids, such as jelly and gum, and hydrogen can make its way through iron and palladium.

We have no time to do more than mention that most wonderful molecular motion which is called electrolysis. Here is an electric current passing through acidulated water, and causing oxygen to appear at one electrode and hydrogen at the other. In the space between, the water is perfectly calm, and yet two opposite currents of oxygen and of hydrogen must be passing through it. The physical theory of this process has been studied by Clausius, who has given reasons for asserting that in ordinary water the molecules are not only moving, but every now and then striking each other with such violence that the oxygen and hydrogen of the molecules part company, and dance about through the crowd, seeking partners which have become dissociated in the same way. In ordinary water these exchanges produce, on the whole, no observable effect, but no sooner does the electromotive force begin to act than it exerts its guiding influence on the unattached molecules, and bends the course of each toward its proper electrode, till the moment when, meeting with an unappropriated molecule of the opposite kind, it enters again into a more or less permanent union with it till it is again dissociated by another shock. Electrolysis, therefore, is a kind of diffusion assisted by electromotive force.

Another branch of molecular science is that which relates to the exchange of molecules between a liquid and a gas. It includes the theory of evaporation and condensation, in which the gas in question is the vapor of the liquid, and also the theory of the absorption of a gas by a liquid of a different substance. The researches of Dr. Andrews on the relations between the liquid and the gaseous state have shown us that though the statements in our own elementary text-books may be so neatly expressed that they appear almost self-evident, their true interpretation may involve some principle so profound that, till the right man has laid hold of it, no one ever suspects that anything is left to be discovered.

These, then, are some of the fields from which the data of molecular science are

gathered. We may divide the ultimate results into three ranks, according to the completeness of our knowledge of them.

To the first rank belong the relative masses of the molecules of different gases, and their velocities in metres per second. These data are obtained from experiments on the pressure and density of gases, and are known to a high degree of precision.

In the second rank we must place the relative size of the molecules of different gases, the length of their mean paths, and the number of collisions in a second. These quantities are deduced from experiments on the three kinds of diffusion. Their received values must be regarded as rough approximations till the methods of experimenting are greatly improved.

There is another set of quantities which we must place in the third rank, because our knowledge of them is neither precise, as in the first rank, nor approximate, as in the second, but is only as yet of the nature of a probable conjecture. These are the absolute mass of a molecule, its absolute diameter, and the number of molecules in a cubic centimetre. We know the relative masses of different molecules with great accuracy, and we know their relative diameters approximately. From these we can deduce the relative densities of the molecules themselves. So far we are on firm ground.

The great resistance of liquids to compression makes it probable that their molecules must be at about the same distance from each other as that at which two molecules of the same substance in the gaseous form act on each other during an encounter. This conjecture has been put to the test by Lorenz Meyer, who has compared the densities of different liquids with the calculated relative densities of the molecules of their vapors, and has found a remarkable correspondence between them.

Now Loschmidt has deduced from the dynamical theory the following remarkable proportion:—As the volume of a gas is to the combined volume of all the molecules contained in it, so is the mean path of a molecule to one-eighth of the diameter of a molecule.

Assuming that the volume of the substance when reduced to the liquid form, is not much greater than the combined volume of the molecules, we obtain from this proportion the diameter of a molecule. In this way Loschmidt, in 1865, made the first estimate of the diameter of a molecule. Independently of him and of each other, Mr. Stoney, in 1868, and Sir W. Thomson, in 1870, published results of a similar kind, those of Thomson being deduced not only in this way, but from considerations derived from the thickness of soap bubbles, and from the electric properties of metals.

According to the table, which I have calculated from Loschmidt's data, the size of the molecules of hydrogen is such that about two million of them in a row would occupy a millimetre, and a million million million million of them would weigh between four and five grammes.

In a cubic centimetre of any gas at standard pressure and temperature there are about nineteen million million million molecules. All these numbers of the third rank are, I need not tell you, to be regarded as at present conjectural. In order to warrant us in putting any confidence in numbers obtained in this way, we should have to compare together a greater number of independent data than we have as yet obtained, and to show that they lead to consistent results.

Thus far we have been considering molecular science as an inquiry into natural phenomena. But though the professed aim of all scientific work is to unravel the secrets of nature, it has another effect, not less valuable, on the mind of the worker. It leaves him in possession of methods which nothing but scientific work could have led him to invent, and it places him in a position from which many regions of nature, besides that which he has been studying, appear under a new aspect.

The study of molecules has developed a method of its own, and it has also opened up new views of nature.

When Lucretius wishes us to form a mental representation of the motion of atoms, he tells us to look at a sunbeam shining through a darkened room (the same instrument of research by which Dr. Tyndall makes visible to us the dust we breathe), and to observe the motes which chase each other in all directions through it. This motion of the visible motes, he tells us, is but a result of the far more complicated motion of the invisible atoms which knock the motes about. In his dream of nature, as Tennyson tells us, he

> "saw the flaring atom-streams
> And torrents of her myriad universe,
> Ruining along the illimitable inane,

Fly on to clash together again, and make
Another and another frame of things
Forever."

And it is no wonder that he should have attempted to burst the bonds of fate by making his atoms deviate from their courses at quite uncertain times and places, thus attributing to them a kind of irrational free will, which, on his materialistic theory, is the only explanation of that power of voluntary action of which we ourselves are conscious.

As long as we have to deal with only two molecules, and have all the data given us, we can calculate the result of their encounter; but when we have to deal with millions of molecules, each of which has millions of encounters in a second, the complexity of the problem seems to shut out all hope of a legitimate solution.

The modern atomists have therefore adopted a method which is, I believe, new in the department of mathematical physics, though it has long been in use in the Section of Statistics. When the working members of Section F get hold of a Report of the Census or any other document containing the numerical data of Economic and Social Science, they begin by distributing the whole population into groups, according to age, income tax, education, religious belief, or criminal convictions. The number of individuals is far too great to allow of their tracing the history of each separately, so that, in order to reduce their labor within human limits, they concentrate their attention on a small number of artificial groups. The varying number of individuals in each group, and not the varying state of each individual, is the primary datum from which they work.

This, of course, is not the only method of studying human nature. We may observe the conduct of individual men and compare it with that conduct which their previous character and their present circumstances, according to the best existing theory, would lead us to expect. Those who practise this method endeavor to improve their knowledge of the elements of human nature in much the same way as an astronomer corrects the elements of a planet by comparing its actual position with that deduced from the received elements. The study of human natnre by parents and schoolmasters, by historians and statesmen, is, therefore, to be distinguished from that carried on by registrars and tabulators, and by those statesmen who put their faith in figures. The one may be called the historical, and the other the statistical method.

The equations of dynamics completely express the laws of the historical method as applied to matter, but the application of these equations implies a perfect knowledge of all the data. But the smallest portion of matter which we can subject to experiment consists of millions of molecules, not one of which even becomes individually sensible to us. We cannot, therefore, ascertain the actual motion of any one of these molecules, so that we are obliged to abandon the strict historical method, and to adopt the statistical method of dealing with large groups of molecules.

The data of the statistical method as applied to molecular science are the sums of large numbers of molecular quantities. In studying the relations between quantities of this kind, we meet with a new kind of regularity, the regularity of averages, which we can depend upon quite sufficiently for all practical purposes, but which can make no claim to that character of absolute precision which belongs to the laws of abstract dynamics.

Thus molecular science teaches us that our experiments can never give us anything more than statistical information, and that no law deduced from them can pretend to absolute precision. But when we pass from the contemplation of our experiments to that of the molecules themselves, we leave the world of chance and change, and enter a region where everything is certain and immutable.

The molecules are conformed to a constant type with a precision which is not to be found in the sensible properties of the bodies which they constitute. In the first place the mass of each individual molecule, and all its other properties, are absolutely unalterable. In the second place the properties of all molecules of the same kind are absolutely identical.

Let us consider the properties of two kinds of molecules, those of oxygen and those of hydrogen.

We can procure specimens of oxygen from very different sources—from the air, from water, from rocks of every geological epoch. The history of these specimens has been very different, and if, during thousands of years, difference of circumstances could produce difference of properties, these specimens of oxygen would show it.

In like manner we may procure hydrogen from water, from coal, or, as Graham did, from meteoric iron. Take two litres of any specimen of hydrogen, it will combine with exactly one litre of any specimen of oxygen, and will form exactly two litres of the vapor of water.

Now if, during the whole previous history of either specimen, whether imprisoned in the rocks, flowing in the sea, or careering through unknown regions with the meteorites, any modification of the molecules had taken place, these relations would no longer be preserved.

But we have another and an entirely different method of comparing the properties of molecules. The molecule, though indestructible, is not a hard rigid body, but is capable of internal movements, and when these are excited it emits rays, the wavelength of which is a measure of the time of vibration of the molecule.

By means of the spectroscope the wavelengths of different kinds of light may be compared to within one ten-thousandth part. In this way it has been ascertained, not only that molecules taken from every specimen of hydrogen in our laboratories have the same set of periods of vibration, but that light, having the same set of periods of vibration, is emitted from the sun and from the fixed stars.

We are thus assured that molecules of the same nature as those of our hydrogen exist in those distant regions, or at least did exist when the light by which we see them was emitted.

From a comparison of the dimensions of the buildings of the Egyptians with those of the Greeks, it appears that they have a common measure. Hence, even if no ancient author had recorded the fact that the two nations employed the same cubit as a standard of length, we might prove it from the buildings themselves. We should also be justified in asserting that at some time or other a material standard of length must have been carried from one country to the other, or that both countries had obtained their standards from a common source.

But in the heavens we discover by their light, and by their light alone, stars so distant from each other that no material thing can ever have passed from one to another, and yet this light, which is to us the sole evidence of the existence of these distant worlds, tells us also that each of them is built up of molecules of the same kinds as those which we find on earth. A molecule of hydrogen, for example, whether in Sirius or in Arcturus, executes its vibrations in precisely the same time.

Each molecule, therefore, throughout the universe, bears impressed on it the stamp of a metric system as distinctly as does the metre of the Archives of Paris, or the double royal cubit of the Temple of Karnac.

No theory of evolution can be formed to account for the similarity of molecules, for evolution necessarily implies continuous change, and the molecule is incapable of growth or decay, of generation or destruction.

None of the processes of Nature, since the time when Nature began, have produced the slightest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecules or the identity of their properties to the operation of any of the causes which we call natural.

On the other hand, the exact quality of each molecule to all others of the same kind gives it, as Sir John Herschell has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self-existent.

Thus we have been led, along a strictly scientific path, very near to the point at which Science must stop. Not that Science is debarred from studying the internal mechanism of a molecule which she cannot take to pieces, any more than from investigating an organism which she cannot put together.

But in tracing back the history of matter, Science is arrested when she assures herself, on the one hand, that the molecule has been made, and on the other that it has not been made by any of the processes we call natural.

Science is incompetent to reason upon the creation of matter itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created.

It is only when we contemplate, not matter in itself, but the form in which it actually exists, that our mind finds something on which it can lay hold.

That matter, as such, should have cer-

tain fundamental properties—that it should exist in space and be capable of motion; that its motion should be persistent, and so on, are truths which may, for anything we know, be of the kind which metaphysicians call necessary. We may use our knowledge of such truths for purposes of deduction, but we have no data for speculating as to their origin.

But that there should be exactly so much matter and no more in every molecule of hydrogen is a fact of a very different order. We have here a particular distribution of matter—a "collocation"—to use the expression of Dr. Chalmers, of things which we have no difficulty in imagining to have been arranged otherwise.

The form and dimensions of the orbits of the planets, for instance, are not determined by any law of nature, but depend upon a particular collocation of matter. The same is the case with respect to the size of the earth, from which the standard of what is called the metrical system has been derived. But these astronomical and terrestrial magnitudes are far inferior in scientific importance to that most fundamental of all standards which forms the base of the molecular system. Natural causes, as we know, are at work, which tend to modify, if they do not at length destroy, all the arrangements and dimensions of the earth and the whole solar system. But though in the course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules out of which these systems are built—the foundation stones of the material universe—remain unbroken and unworn.

They continue this day as they were created, perfect in number and measure and weight, and from the ineffaceable characters impressed on them we may learn that those aspirations after accuracy in measurement, truth in statement, and justice in action, which we reckon among our noblest attributes as men, are ours because they are essential constituents of the image of Him who, in the beginning, created not only the heaven and the earth, but the materials of which heaven and earth consist.

Table of Molecular Data.

	Hydrogen.	Oxygen.	Carbonic oxide.	Carbonic acid.
Mass of molecule (hydrogen = 1)	1	16	14	22
Rank I.—Velocity (of mean square), metres per second at 0° C.	1859	465	497	396
Mean path, tenth-metres	965	560	482	379
Rank II.—Collisions in a second (millions)	17750	7646	9489	9720
Diameter, tenth-metre	5.8	7 6	8 3	9 3
Rank III.—Mass, twenty-fifth grammes	46	736	644	1012

Table of Diffusion: $\frac{(\text{centimetre})^2}{\text{second}}$ measure.

	Calculated.	Observed.	
H & O	0.7086	0.7214	Diffusion of matter observed by Loschmidt.
H & CO	0.6519	0.6422	
H & CO_2	0.5575	0.5558	
O & CO	0 1807	0.1862	
O & CO_2	0.1427	0.1409	
CO & CO_2	0.1386	0.1406	
H	1.2990	1.49	Diffusion of momentum, Graham and Meyer.
O	0.1884	0 213	
CO	0 1748	0.212	
CO_2	0.1087	0.117	
Air	.....	0 256	Diffusion of temperature observed by Stefan.
Copper	.....	1.077	
Iron	.....	0.183	
Cane sugar in water		0.00000365	Voit.
Diffusion in a day		0.3144	
Salt in water		0.00000116	Fick.

PHOSPHOR BRONZE.

From "Iron."

An extended manipulation and study of this alloy has resulted in a more complete knowledge of its general properties, and, consequently, has led to greater perfection in its application. A greater resistance and elasticity have been discovered than had been previously accomplished, and with these there has been acquired a method of producing, with ease and certainty, an alloy in which one or other of these qualities are predominant, combined with a durability that can be regulated according to the work to which it is to be applied.

For the purpose of illustrating these results, we quote the following experiments made by Mr. Kirkaldy, simply noting that while the composition of the metal was in each case identical, its preparation was subject to certain modifications. In the following table the absolute resistance in English avoirdupois pounds per square inch, the elastic resistance in the same terms, and the permanent elongation per cent., are afforded.

Alloy.	Absolute resistance in pounds per sq. in.	Resistance of elasticity in pounds per sq. in.	Permanent elongation per cent.
1	74,966	55,800	3.53
2	73,987	55,200	3 20
3	63,653	40,500	9 40
4	54,060	26,300	31 30
5	50,120	21,700	59.10

In Prussia the Minister of Public Works, impressed with the important properties of this alloy, has in the public interest, ordered a series of experiments to be undertaken similar to those which, some eight years ago, were tried on metals employed in some departments of railway materiel. We may refer to the more important results of these experiments.

It was formerly believed, and this opinion has been verified by the Berlin experiments, that both steel and iron, after being repeatedly subjected to traction, torsion, or flexion, inferior to their supposed absolute power of resistance, at last break, even at a much less strain than is due to them, most probably owing to a change of their molecular structure. These experiments have shown that the number of strains of tension, deflection, and torsion that a metal can bear is in the inverse ratio of the amount of force to which they have been subjected.

The Prussian Government wish to prove that a metal, whose absolute and elastic resistance has been determined, can support with perfect security a definite number of tests equally determined, and inferior to the units of resistance. Consequent on this they resolve that any portion of such material, as, for example, an axle, should only be submitted to a limited service in regard to time, partly because of the resistance of the metal employed, and also in regard to the curves it has to pass over. MM. Reuleaux and Spangenberg have been employed by the Government to carry out the experiments incident to the question. Those who are desirous of knowing the manner in which the trials were to be conducted, and the apparatus to be employed, are referred to a work by M. A. Wöhler, entitled "Uber die festigkeitsversuche mit Eisen und Stahl," Berlin, 1870, Ernst u. Kom.

In the fire experiments, instituted by way of comparison between the phosphor and ordinary bronze, begun in April, 1873, and ended towards the middle of May, the phosphor-bronze had been subjected to 408,230 efforts of tension, with a force of 200 quintals per square inch, while the first bar of common bronze was broken before it could be submitted to the strain, and a second resisted only 4,200 of such efforts.

A second bar of phosphor-bronze, loaded with 250 quintals per square inch, has sustained continuously 147,840 efforts without fracture.

In an experiment on bending or flexure, it was found that, with a maximum strain of 200 quintals on its external fibres, a bar of phosphor-bronze broke, but only in respect to its external fibres, where the greatest amount of tension took place, and after 862,980 flexions; while a similar bar of ordinary bronze broke completely after 102,650. Lastly, a bar of phosphor-bronze, bearing a strain of 180 quintals per square inch, was submitted to 1,260,000 flexions without showing signs of deterioration.

A kind of phosphor-bronze, made of materials intended especially to bear the effects of friction, has been employed for several

years by railway companies, especially the Great Central of Belgium, which has adopted it exclusively for numerous purposes where great friction is incident. It has been found by Belgian and Prussian firms that in its use for axle and similar bearings its durability is equal to five times that of ordinary bronze. The following are some of its special applications for industrial and other purposes:—

PINIONS AND TOOTH-WHEELS.

MM. V. Gelliaux at Charleroi, Blondiaux at Thy-le-Chateau, Thorneycroft at Wolverhampton, De Wendel at Hayange, among many others, have used pinions and tooth-wheels made of phosphor-bronze in instances where the separate parts might run the risk of sudden and violent shocks. They have proved that such pinions never break, while it is found in long practice that the teeth last double the time of those made of ordinary bronze. Remarks on this point will be found in the "Bulletin du Musée de l'Industrie." The alloy has, for similar reasons, been much employed for various horological purposes.

TUYERES.

An article appeared in the "Bulletin du Musée de l'Industrie" speaking highly in praise of the use of phosphor-bronze as a material for tuyeres. It proved that they last far longer than similar tuyeres of ordinary bronze, and that after a year's use they presented neither sign of fissure nor incrustation by scoriæ of the furnace. These tuyeres have been tried in England and France, and in Germany their use has become greatly extended.

PUMP CYLINDERS, ETC.

The great resistance which phosphor-bronze possesses makes it highly suitable for the construction of barrels of all kinds of pumps, but especially for hydraulic presses. Mr. Merryweather, of London, has employed it in the construction of all the steam fire engines that he has placed at the disposal of the authorities of the Vienna Exhibition. Messrs. Mackean and Co. have extensively employed it for various purposes in their contract for works, in connection with the St. Gothard Tunnel construction.

PISTON PACKING.

The application of phosphor-bronze has given excellent results for this purpose. Its great elasticity and the small amount of friction of its surface gives it much advantage over the ordinary steel packing.

WIRE.

The great elasticity and tenacity of the phosphor-bronze gives it at least an equal value, as a wire, with any other metal susceptible of being drawn. This is shown by the following table, which gives the results of Mr. Kirkaldy's experiments:—

Metal used.	Resistance per square inch in pounds avoirdupois.		Number of torsions in a length of five inches.		Final elongation per cent.
	Drawn.	Annealed.	Drawn.	Annealed.	
Phosphor-bronze	102,750	49,351	6.7	87	37.5
" "	120,957	47,787	22.3	52	34.1
" "	120,950	53,381	13.0	124	42.4
" "	139,141	54,153	17.3	53	44.9
" "	159,515	58,853	13.3	66	46.6
" "	151,119	64,569	15.8	60	42.8
Copper	63,122	37,602	86.7	96	34.1
Steel	120,976	74,637	22.4	79	10.9
Best charcoal iron	65,834	46,160	48.0	87	28.0

WIRE CABLES AND ROPES.

Owing to its great resistance and elasticity, phosphor-bronze has, with other alloys of copper, the advantage of not becoming crystalline under the action of repeated shocks, as is the case with iron and steel. It is, therefore, eminently fitted for making wire rope, as a core for submarine cables and inland wires, etc. The first cost is, perhaps, high, but this is more than counterbalanced by the length of time that a wire of phosphor-bronze retains its essential qualities. The material is unacted on by corrosive liquids as found in mines, etc., and also is not subject to atmospheric action.

SHEETS, ETC.

Phosphor-bronze is readily rolled or beaten out into sheets. In Russia it has been used as a material for cartridge sheathing, and specimens have stood 120 trials without tearing. Sheets of the alloy stand the action of sea water much better than copper. In a comparative expériment made at Blankenberghe, lasting over a period of six months, between the best English copper and phosphor-bronze, the following results were arrived at:—

Thickness of the sheets = 0 236 in.	Weight before immersion in pounds.	Weight after immersion in pounds.	Loss of weight.	
			In pounds.	Per cent.
Sheet of copper	74.4	72.2	2 2	3 015
Ditto	88.9	86.2	2.7	3 100
Sheet of phosphor-bronze	69.5	68.75	0.75	1 123
Ditto	114.3	112.97	1.33	1 195

The loss in weight, therefore, due to the oxidizing action of sea water during the six months' trial, averaged for the English copper 3.058 per cent., while that of the phosphor-bronze was but 1.158 per cent.

It was desirable to ascertain the resistance of the alloy to the chemical action of dilute sulphuric acid. For this purpose, on the 22d of last April, two similar sheets of copper and phosphor-bronze were immersed in acid water of 10 deg. Baumé strength, and at the temperature of the surrounding atmosphere. On the 28th of July it was found that the copper had lost 4.15 per cent., and the phosphor-bronze only 2.3 per cent.

Several Governments have experimented on the use of the alloy for making cannons. Without any exception, the result showed a much greater resisting power over that possessed by ordinary bronze. The following instances of the results arrived at will be of general interest.

In Belgium the ordinary bronze gun burst at the second shot, with a charge of 1 k. 250 gr. ($2\frac{3}{4}$ lbs.) of powder and a cylindrical projectile weighing 8 k. 518 gr. ($18\frac{3}{4}$ lbs.). The phosphor-bronze gun supported this charge perfectly; the normal charge was 500 gr. (1 1-10th lb.) of powder, and 3 k. (6 2-3ds) of projectile.

In France, the ordinary bronze gun burst at the second shot, with a charge of 1 k. 500 gr. ($3\frac{1}{2}$ lbs.) of powder and 16 kil. ($35\frac{1}{4}$ lbs.) of projectile, while the phosphor-bronze gun was fired five times with this charge, and burst at the second shot with 1 k. 750 gr. ($3\frac{7}{8}$ lbs.) of powder, and a projectile of 20 kil. (44 lbs.), owing to the wedging of this in the barrel. The normal charge was 0 kil. 550 gr. ($1\frac{3}{8}$ lbs.) of powder and a bomb of 4 kil. (8 4-5ths lbs.).

In Prussia it was shown in firing with the regulation charges, and diminishing, at each 50 shots, the exterior diameter of the chamber, that the phosphor-bronze cannons changed only their dimensions when the thickness of the metal was below that of the dimension of a cannon of the same calibre made of steel.

The Belgian Government has adopted the phosphor-bronze for small arms, and for the harness buckles of all the cavalry.

Besides the Société Montefiore-Levi and Co., at Val-Benoit, Liege, three other companies have been formed for the introduction and sale of phosphor-bronze, viz., in Germany there is G. Hösser and Co., at Iserlohn; in the United States the Phosphor-Bronze Company, at Pittsburg; and in England the Phosphor-Bronze Company, 110 Cannon Street, London, the latter having contributed complete specimens to the Exhibition at Kensington.

WATER-POWER.

From "The Engineer."

The high price of coal seriously affects at this moment the property of certain individuals, firms, and companies, who rely solely on fuel for the production of the power required to drive their factories or workshops. It is to the last degree unlikely that any material reduction will be effected in the price of coal; but it is cer-

tain that if England is to hold her own with other nations, power must in the future take the place of manual labor day by day to a greater extent. There are branches of manufacture, sources of national wealth, such as iron-making, which cannot be carried on at all without fuel; but there are other branches of manufacture, such as cotton spinning and weaving, which require power only, irrespective of the source from which it is supplied, and it is to be regretted that those who carry on such trades should invariably resort to our coal-fields for the power which they require.

In numberless instances the steam-engine could be dispensed with, and water-power employed instead, if manufacturers would but recognize the fact that water-wheels or turbines close to a mill are not necessities, and that the power which resides in a volume of falling water can be utilized in various ways perfectly practicable and ready of application, although they may appear at first sight to be novel and impossible. We propose here to call attention to one or two cases which suggest themselves to us as affording examples of circumstances under which water-power may be utilized with great advantage.

The disposal of sewage is not perhaps a branch of manufacture except when irrigation is employed in the production of grass, and beef, and root crops for the market; but we find that very large sums are annually spent in pumping sewage from a lower to a higher level in order to get rid of it, and steam-engines of great power are not unfrequently employed for the purpose.

We may cite the Metropolitan Main-Drainage Works as an instance. But without resorting to an unique case like this, we may point out that hundreds of sea-side towns are now badly drained because the sewage is not delivered on the top of the tide to be carried out to sea, but is expended on the foreshore at low water, to be carried back to land as the tide rises; and this simply because the cost of the engines and pumps and of the coal required to put them in motion and pump the sewage up to high-water level, is greater than the towns can bear. Yet, if engineers would but recognize the fact, nothing can be easier than to utilize the rise and fall of the tide as a means of raising the sewage to the required level.

To explain our meaning, let us suppose that we have to deal with a small town of, say, 10,000 inhabitants, on the sea-side, and lying low. The sewage from such a town will probably be about 200,000 gallons per day, and this quantity ought to be lifted, say 10 ft., to get rid of it properly. Nothing more is necessary than to construct a couple of tanks on the sea-shore, each capable of holding 100,000 gallons. Both are water and air-tight. One we shall call the sewage, the other the tidal tank. A discharge pipe extends from the top to nearly the bottom of the sewage tank, a pipe connects the upper portions of both tanks; in this pipe there is a valve. The sewage for 12 hours is delivered into one tank. When the tide is at the highest the sea is allowed to flow into the tidal tank. The air compressed by the entrance of the water is forced into the sewage tank, and, pressing on the surface of its contents, the sewage is forced up the discharge pipe, and so cast into the sea at high water. As the tide falls, the sewage tank slowly fills again, the process being repeated twice in the twenty-four hours. The apparatus, if properly constructed, would work almost forever without repairs or renewal; and suitable sluices being employed, could be rendered self-acting.

It must be understood, that we have just sketched the mere outline of a plan which will enable town sewage to be got rid of in many instances in the most satisfactory way without trouble or expense. Into details it is not now our purpose to enter; many of our readers will, no doubt, fill them in for themselves without difficulty. Nor is it to be supposed that the operation of such an apparatus must necessarily be confined to the pumping of sewage. The force of the tides can be utilized in numberless ways to transmit power to a distance. For example, a set of accumulators may, without any wonderful expense, be arranged in any tidal harbor, which will provide a store of power sufficient for working all the dock cranes and other mechanism. Thus each accumulator might consist of a cylinder 10 ft. in diameter and 10 ft. high, displacing roughly 780 cubic feet. If we take the weight of sea water at but 62 lbs. per cubic foot, leaving an ample margin for friction, each of these accumulators would, if fully immersed, lift 48,360 lbs., and if the lift were 10 ft. the work done on each by a tide, which it would restore as the tide fell, would

amount to 483,600 foot-pounds. One such accumulator would keep an ordinary wharf crane at work half a day in lifting light loads. The extension of the system, however, on a large scale, would supply enormous power, easily transmitted to a moderate distance, either in the shape of air or water under pressure. Indeed, there is no reason why all the works in manufacturing towns, when the tide rises and falls through a wide range—as is the case, for example, in the Bristol Channel, where tides 40 ft. high are not unknown—should not be worked by tidal agency alone, without the aid of a pound of coal. No doubt our ideas on this subject will be called impracticable by a few individuals, who, incapable of originating a novel idea themselves, hasten invariably to condemn any proposal made by others; but it would be as reasonable to assert that it is impossible to utilize the enormous power of the tides for commercial purposes, as it would be to assert that steam navigation was a chimera and railroads an idea.

But, abandoning tidal power for the moment, and turning our attention to the force of our streams and rivers, we would call attention to the fact that in but too many instances hundreds, if not thousands, of horse-power are being wasted year by year, and this, too, by men who would gladly use it if they only knew how. For example, mills in abundance may be found erected either on the banks of rivers or two or three miles from them, the rivers being competent to afford all the power required to drive them, notwithstanding which, steam is used instead at a heavy outlay. We can call to mind one instance where a mill, driven by steam power, is situated about two miles below a high fall, and on the banks of a river. The site was selected because barges can come alongside. The mill could not be brought to the fall because the barges could not get up high enough. Steam power is used in consequence, and the force of the fall is wasted. It would have cost much money to construct an aqueduct and lead the water for two miles at a high level to the mill. But it would have been quite practicable to put up a turbine or water-wheel at the fall, and transmit the power for two miles across country by the use of a wire rope. The total cost of such a line complete, competent to transmit 100-horse power indicated, would not exceed £800, unless, indeed, land had to be purchased. Under ordinary circumstances, a turbine or water-wheel capable of developing 100-horse power should not cost more than £700. Thus, for an outlay of £1500 about 100-horse power could be had. A thoroughly good engine, with boilers, chimney-stalk, engine and boiler-house, etc., will not at present prices cost very much less than £1500, if the engine is to work up to 100-horse power. The cost of fuel alone for such an engine working twenty hours a day for 300 days per annum, would reach £1000.

The cost of maintaining the wire-rope line would, we have reason to believe, not exceed one-fourth of this sum; and, whereas at least four attendants would be required to look after the engine in double shifts, one man would be quite competent to attend to the welfare of the rope, and to look after the lubrication of the supporting pulleys, etc. This plan of transmitting power by ropes from water-wheels or turbines is by no means new. It has been extensively employed on the Continent, and it is being adopted on no small scale in the United States. The length of rope used varies from a couple of hundred yards up, and it has never yet been decided what is the limit of distance beyond which a rope cannot be used with advantage.

If we consider how wide a range of country would be opened up if only the power might be dispensed at a distance from the factory, it will be seen that the extension of the system is likely to be fraught with immense benefit. For example, falls often exist near the foot of a hill, at points almost if not quite inaccessible for factory purposes, while two or three miles lower down may be found a thriving town. Here rope transmission would do excellent service.

Again, a fall is two or three miles from a railway; the factory must be near the railway. If, then, power can be led across the country to the mill a great difficulty is disposed of. We have done little more in this article than call attention to a few facts which are, unfortunately, almost universally overlooked; but we hope to return to the subject, and supply some information as to the precise cost of wire-power transmission plant, both as regards its installation and maintenance, which will, we trust, prove interesting and useful to many of our readers.

ARMOR PLATES.

By H. E. BROWN, Esq.

From the "Nautical Magazine."

Armor plates were first used in the construction of ships of war in the case of an iron steam battery for harbor defence, commenced at Hoboken, U. S., in 1844. At the suggestion of the Emperor Napoleon some *floating batteries*, clad with 4-in. armor, were built during the Crimean war, and employed in some of the operations in the Black Sea, but these, as well as some built by our own Admiralty in imitation of them, were of very little use, on account of their clumsy form, and it was not till the advent of the French La Gloire and our own Warrior that it began to be seen that the war-ships of the future would be iron-clads. In 1861, when the Warrior was built, it was believed that, while the thickness of her armor (4½ in.) represented the maximum of weight which a seaworthy steamship could carry on her sides, it, at the same time, provided a defence practically invulnerable. Both these views were soon shown to be defective, and it is now seen to be practicable to build, as well as desirable to have, seagoing masted ships with armor averaging 7 in. in thickness, and in some large ocean cruisers, without masts, 10 to 12 in. of armor have been used on their sides, and 12 to 14 upon their turrets. Nor does this great increase in the thickness of armor constitute the sole advantage which recently constructed ironclads have over the Warrior. Besides the important consideration that the armor is so distributed over the surface of some of our latest ironclads that a belt at the water-line throughout the ship, and other really important parts, are protected, which is not the case with the Warrior, where merely the middle portion of the ship is ironclad, it must be added that armor plates are now better made and are fastened on the ship's side much more securely than formerly. Experiments made at Shoeburyness, under the direction of a committee appointed for the purpose, have furnished data upon which have, from time to time, been determined the thickness and nature of the backing behind the armor, and the character of the fastenings by which the armor is secured to the ship.

The extent of surface to be clad with iron in any ship and the thickness of her armor are determined by her designer, and in reference to her other qualifications. A model is made at the dockyard, and on it the size and dimensions of the separate plates are planned, and an account of these particulars, and also of the form of each plate, is sent to the manufacturer. Armor plates are usually from 15 to 18 ft. long, and from 3 to 4 ft. wide. Two methods of manufacturiug them—namely, *hammering* and *rolling*—have been tried, and each has had its advocates, but the Government of this country has decided in favor of the latter, and for the last seven or eight years all armor plates used for the ships of the Royal Navy have been *rolled* plates. The firms who manufacture most of the armor used in the construction of the English ironclads are Sir John Brown & Co., of the Atlas Works, Sheffield, and Messrs. Cammell & Co., of the Cyclops Works, Sheffield. The Thames Iron Company, who were the builders of the Warrior, still adhere to *hammered* in preference to *rolled* plates, and many ships built for foreign Governments have this description of armor. The process of rolling plates is thus described by Sir John Brown:—"Bars 12 in. broad and 1 in. thick are first rolled, five of these are then piled on and rolled into a rough slab, two of these slabs are now rolled into a plate 2½ in. thick, and, finally, four of these 2½ in. plates are piled and then rolled into the finished 4½ in. plate." It will thus be seen that pieces of iron of an aggregate thickness of 20 in. are, in the process of manufacture, rolled out into one plate 4½ in. thick. The rolling is performed by means of two heavy cylindrical rollers, one placed vertically over the other, the lower one suspended at a fixed height, the upper one movable up or down, so that the width of the opening between them may be varied at pleasure. The rollers turn in opposite directions, each towards the opening between them on the side next the furnace in which the iron is heated, so that a mass of iron passed in between them is forced through by their rotation. They are turned by steam power. The rollers being set at a distance from each other a little

less than the thickness of the iron in the furnace, the heated metal is brought out and placed between them, and is at once rolled through, coming out on the other side reduced in thickness, but of increased length and breadth. The distance between the rollers is then decreased, and the iron passed through again, and so on, until it is of the required thickness. By the immense pressure thus brought to bear upon the heated metals, the various pieces of which it is composed are thoroughly welded into one mass. In the manufacture of hammered plates the welding is effected by blows from a steam hammer, instead of by rolling.

Before the plates are sent to the dockyard, one or more are chosen at random by a Government official to be tested. The testing is performed at Portsmouth, on board the Thunderer, an old wooden ship. The plates are fastened to a target erected at one end of the ship, and shots are fired at them from guns of prescribed calibre, in a battery at the other end, the men being protected from the splinters of the shot by a casemate. If the plate does not stand the test satisfactorily, the lot from which it was selected is rejected. This system of tests secures as good an article as it is possible to make. During the first few years of the manufacture it was found that the plates were often split and cracked by the shot, in the neighborhood of the holes which had to be bored through them for the screws or bolts by which they were attached to the targets. It was thus assumed that these holes were necessarily a source of great weakness, and many schemes were proposed for connecting plates with the ship's side in ways by which this important defect might be avoided. One was, that an iron frame should be attached to the ship, and the plate dropped into it, the edges of the frame being afterwards beaten over to secure the plate in its place. The necessity for anything of this kind has been obviated, by the great improvements which have been effected in the quality of the armor; the metal now used is so tenacious that it is scarcely any weaker in the neighborhood of a bolt-hole than in any other place. The superiority of the armor of the present day over that made ten years ago was fully exemplified in the recent experiments on the turret of the Glatton. A hole was punched through one of her 14-in. plates by the shot, but there was no other damage done to the plate than the mere penetration. Under similar circumstances, in the case of plates experimented upon at Shoeburyness, some years ago, there would be seen large cracks radiating from the shot hole, producing a complete separation of the plate as far as the nearest bolt-holes, and in many cases the armor plate would have been broken in two or three pieces. The price of armor plates, some little time ago, was about £30 per ton; their value now is of course subject to the same fluctuation as that of other iron.

Armor plates are usually bent to the shape required by hydraulic pressure. A block of cast-iron having its upper surface hollow (of the same shape as the armor plate is to be), is placed upon the piston-rod of the hydraulic press. Upon this is laid the armor plate, and above it is constructed a framework of iron bars, firmly fixed, so that their under sides form a surface of a corresponding shape to the block below. When the plate is in its position upon the cast-iron block, the pressure is applied, the effect being that the plate is lifted slowly, and brought in contact with the framework above, and so gradually squeezed into the shape required. Before being bent, the plates are carefully and gradually heated in a furnace, the required temperature being indicated by a bright red color in the iron; if it were made hotter it would be liable to be indented, or spread out laterally, in the process of bending; if not so hot, there would be a danger of the plate cracking when subject to great pressure.

An important element in the armoring of ships, is the cushion of wood which is placed between the armor and the main structure of the ship. The part of the ship to which the armor is attached is built up of iron ribs and plating, and is so constructed as to be complete, both as regards strength and water-tightness, before either the armor or wood backing is put on. The armor is rather a source of weakness to the structure than otherwise, and if its edges were not accurately fitted, so as to prevent any possibility of the plates moving, its working would, in a heavy sea, seriously endanger the ship. In the Warrior, the wood behind the armor is 1½ ft. thick; in ships of more recent construction, it is generally from 10 to 12 in.; but, in some cases, there are two layers of backing with an intermediate iron skin. During the building

of the earlier ironclads, there was much discussion about the relative efficiency of different kinds of backing. Some very eminent engineers and naval architects believed that a ship's side entirely made of iron would offer more resistance to shot than would armor and wood backing of the same weight per square foot of surface—in other words, that a 6-in. armor plate was more effective than a 5-in. plate with a 9-in. thickness of teak backing behind it. It was proved by experiment that such was not the case, and that the latter was much superior to the former arrangement; it is possible, however, that the improved quality of the iron, taken in conjunction with the perishable nature of the wood, may ultimately lead to a reconsideration of the whole question, and perhaps to the abandonment of backing behind armor. Among the various kinds of backing which have been proposed are india-rubber, compressed cotton-wool, millboard, and even water in tanks; not one of them, however, has proved to be as good as wood. Teak is the kind of wood generally used, both from its durability and its freedom from acids, which would corrode the iron. The logs of teak are usually placed on the ship's side in the direction of her length. If there are two layers, the logs of the outer one are arranged vertically so as to cross the others. The backing is fastened to the iron skin of the ship, and all the seams in it are well caulked to add to its rigidity as well as to render it water-tight. Previous to an armor plate being placed on the ship, a coating of a glue, manufactured for this purpose, is spread (hot) upon the wood, the surface of the plate also being slightly heated, and thus all inequalities in the attached surfaces are filled up.

The means of connecting the armor to the ship has, like almost every other detail in the construction of ironclads, been a fruitful subject of debate. The French use large screws, which pass loosely through holes in the armor and into the wood backing, and by the hold of the screw in the wood, keep the armor in its place. A great disadvantage attending this is, that in the event of the armor being bent by shot, it is all but impossible to get the screws out. In the English ironclads, bolts pass through the armor, wood backing, and iron skin of the ship, having a screw upon their inner end, upon which a nut is screwed up after the bolt is in its place. The bolt is driven through the wood, and has thus its tightness in the wood as well as the screw-nut on its end to keep it fast. In the French system it is found that the effect of the firing of shot is to drag the screw out of its hole in the wood, thus allowing the armor plate to curl outward, while, on the other hand, in the case of the nut-and-screw bolt, the bolt breaks off at its weakest point—*i. e.*, the beginning of the screw. To prevent this an india-rubber ring is placed upon the bolt, enclosed in an iron cup ring, and having another iron ring between the india-rubber and the screw nut. The elastic ring admits of the bolt being drawn out slightly in response to the blow of a shot, and thus tends to break the shock which would otherwise cut the bolt. The danger to the fastenings of the armor is produced, as has been indicated, by the tendency which plates have to bend when struck by a shot. The plate can only be slightly forced in at the place where it is struck, because of the support behind; the consequence is, a tendency to spring out on all sides of the shot mark.

The armor plates used by the Americans in the construction of their monitors, were not welded together, as are those used by our own Government; they were made by simply connecting thin plates together by means of rivets—thus, a 10-in. plate would be made by riveting together ten 1-in. plates. By experiment it has been ascertained, that a good 5-in. rolled plate is much more capable of resisting shot than 10-in. armor built up in this fashion. In conclusion, it may be remarked, that it is not enough in comparing two ironclads of similar design, to say that they have each armor of a certain thickness; the quality of the armor plates, the accuracy with which they were fitted on the ship, and the nature of the fastenings by which they are kept in place, may so affect the question as to give one ship a decided superiority over another which is said to be as strong.

The Andover Iron Company, Phillipsburg, New Jersey, has three blast furnaces, which have been in blast (August 11) as follows: No. 1 furnace, 7 years 8 months; No. 2 furnace, 6 years 7 months; No. 3 furnace, 5 years 7 months. Is there another furnace in the country with better "bottom" than either of these?

AERO STEAM ENGINES.

From "The Engineer."

The use of expanding air instead of steam as a means of obtaining motive power has long been a favorite device with many engineers. Ericsson, Siemens, Wenham, and several others, have all tried to construct a really effective hot-air engine; and it is not too much to say that they have one and all failed. Their theory is perfect, and the machines in working display no marked departure from the theory on which their principles of action are based. Hot-air engines have, indeed, proved eminently economical in fuel, and it is therefore extremely desirable that they should give as much satisfaction in other respects to those who use them, but this they have never yet done. They all fail because of the difficulty of maintaining efficient lubrication in the first place; and in the second, because various parts of the complete machine are liable to distortion from the long-continued action of very high temperatures on the metal of which they are made. It may be taken for granted, that no system of constructing hot-air engines has yet been brought prominently before the world which bids fair to be even moderately successful in the commercial sense of the word. As, however, an air engine is more economical in principle and practice than a steam engine, and as the last is a commercially possible machine, whereas the first is not, inventors have proposed to combine the two, and so to construct a machine, which, though less economical than a hot-air engine, pure and simple, as regards fuel, shall be more economical than any steam engine. Several attempts to introduce this principle have been made from time to time within the last few years, all with more or less success, and it is proper to say that whatever the results obtained, whether satisfactory as regards economy of fuel or not, we have no recorded instance where failure took place under the combined air and steam system from want of efficient lubrication, or because of distortion or overheating of a metal surface.

Aero steam engines may be divided into three classes. In the first we have machines in which the proportion of air used is very considerable as compared with the volume of the steam. In these engines, indeed, saturated steam is used as a means of lubricating the surfaces more than anything else, the production of the steam frequently taking place within the cylinder, the heated sides of which evaporate a jet or spray of water, thrown in at each stroke. It is quite possible under this arrangement, however, to use so little water that the engine becomes to all intents and purposes a hot-air engine only, with all its defects. In the second class, we have the air introduced into the steam pipe or valve chest, and in considerable quantity; Parker's system, often described in our pages, comes into this class. And, lastly, we have the system under which air is pumped into the water in the boiler; Warsop's aero steam engine is an excellent example of this class. In considering the relative merits of the three systems, regard must be had to various conditions of working. For the present we may almost disregard the first scheme, owing to certain practical difficulties not yet overcome in proportioning the quantity of water injected to the work to be done, in distributing it equally, and in averting the risk of injury which may follow on the sudden fall of temperature caused at the moment the water is injected, by its rapid evaporation. There is, however, something to be said in favor of the system; but we believe that the same end can be attained with less trouble, and far more satisfactorily upon the whole, by some such arrangement as that of Mr. Parker's, by which the air is combined with the steam before reaching the cylinder. On three distinct occasions we have carried out elaborate experiments with engines working on Parker's system, and invariably with the same result, namely, that if the sensible temperature of the air injected is brought up to the sensible temperature of the steam, by utilizing the waste heat of the flues, etc.—a comparatively easy operation—an economy of from 25 per cent. to 40 per cent. may be effected in fuel without in any way endangering the cylinder. But Parker's system is not applicable to condensing engines; nor will a Parker engine, working, as it must of necessity do, at a comparatively low pressure with a late cut-off, compete with a first-class condensing engine working with high-pressure steam and an early cut-off; but this defect is not due to the use of air,

but the manner of using it. Mr. Parker uses an inducing current of steam to take the air in, and the pressure of air and steam in the cylinder never exceeds one-third of the boiler pressure. However, there are circumstances, where engines are now working much throttled, to which the Parker system could be applied with a direct saving of, as we have said, from 25 per cent. to 40 per cent., but it requires some discrimination to say where it may and where it may not be applied with benefit. Of course, if we give up the induced current device, and simply pump the air into the steam pipe, we can maintain any pressure we please less than that in the boiler, and it will then have to be decided exactly how much air it is desirable to introduce. Before going further it will be well to point out here that, from some cause at present not completely explained, the mixture of a small quantity of air, say 6 per cent. or 7 per cent., with steam, tends powerfully to prevent condensation in the cylinder. We believe that this fact was first publicly stated by the late Professor Rankine in this journal. His premature death unfortunately prevented him from carrying out any experiments on the subject; but Prof. Osborne Reynolds has done that which Rankine did not live to do, and he has communicated the result of his experiments in a valuable paper to the Royal Society. The results arrived at by Professor Reynolds are, as we have stated, that, speaking broadly, an admixture of about 6 or 7 per cent. of air with steam tends powerfully to arrest condensation and promote economy.

Returning now to the point we are discussing, namely, the proper quantity of air to introduce, it may be stated that as cold air should never under any circumstances be pumped in amongst the steam, so, as much air may be used as can be supplied at the same sensible temperature as the steam, the air to be heated by the waste gas in the flues. Of course it might be possible in this way, by using a very small boiler and a big grate, to introduce more hot air than would be advisable, and the engine would then come to be ranked in Class I. In practice, however, no such result is likely to take place, and the quantity of heated air to be obtained with the aid of the waste gas will seldom exceed 10 or 12 per cent., if so much, of the whole volume of fluid passing through the engine. It is obvious that if the introduction of this 10 or 12 per cent. is not attended with loss of pressure, and that the draught in the chimney is not too much reduced, that then the direct saving will be measured by regarding each foot of air used as a foot of steam saved; the air being measured, however, not by its absolute volume in the cylinder, but by its relative volume as compared with that which it possessed before it passed through the heating coils. Thus, if we take 1 lb. of air at 65 deg. to measure 13.5 cubic feet, which is not far from the truth, then at 212 deg. that pound of air would occupy 17 cubic feet nearly, and the percentage of saving effected in such a case would be represented by $17 - 13.5 = 3.5$ cubic feet only, and so on for higher pressures. Indeed, at atmospheric pressure, or 212 deg., no benefit would be gained except that due to the fact that the air-pump would have to extract but 13.5 ft. of air, while 17 ft. passed through the engine. In theory there is a direct saving to be effected by using air instead of steam, owing to the difference in specific heats, etc., of the two fluids; but into this question we shall not enter now, preferring to confine our attention to the fact that air may be used to catch up and save waste heat in a way that is impossible with steam, because the sensible temperature of the steam is little below that of the flues, and so in properly constructed boilers there is not much heat to take up; and secondly, because if there was, the steam would be superheated at the risk of destroying the cylinder. It must not be forgotten, however, that the temperature of the air is greatly augmented by the compression required to force it into the boiler; and if the flue temperature be a little greater than that of the air, then there will be very small or no advantage derived from the heating coils; and the rise in sensible temperature is very considerable, for if we assume the volume of a pound of air at 32 deg. as 12.5 cubic feet, then the volume at any other temperature T will be

$$12.5 \times \frac{T + 461 \text{ deg.}}{493 \text{ deg.}}.$$

If we take the available flue temperature as 400 deg.—which would correspond to steam of nearly 250 lbs. pressure—we shall find that 12.5 cubic feet of air would only be dilated into 21.8 ft. by a rise of $400 - 32 = 368$ deg. But if the volume remains

unaltered, then the pressure would be increased to about 27 lbs. only,* from which it will be seen that an apparently insignificant amount of work done by the compressing pump will render the flue temperatures unavailable as a means of economy, unless under conditions which only obtain in boilers with deficient heating surface and fixed very sharply. Thus, the up-take temperature in marine boilers is often 800 deg., and if the pressure in the boiler is at the same time moderate—say 20 lbs. or so—then an absolute economy would be effected by the use of air-heating coils, which would be impossible if steam were used instead of air, because the steam would become so far superheated that the cylinders would be ruined long before it could reach a temperature of nearly 800 deg. It is quite possible, however, that air at 800 deg. might be pumped into the steam space; but in this case the effect would be that the air would fall to the temperature of the steam, the efficiency of the mixture being slightly augmented either by superheating to a perfectly safe extent, or by merely effecting the evaporation of the suspended particles of water in the steam.

We come now to the third system, which consists in pumping air into the water in the boiler. As we have shown, the mere act of condensing the air—that is to say, raising it to the required pressure—will also with most stationary boilers, elevate its temperature so much that nothing will be gained by passing the air through coils in the flues; but the air so introduced does beyond question operate economically in a way which, as we have said, has not yet been fully explained. In the first place, it promotes the conversion of water into steam in much the same way that certain chemical operations are facilitated by the presence of bodies which, taking no apparently active part in the chemical phenomena which go on, and remaining unaffected themselves, yet induce an active action which without them is wholly wanting. It has long been known, indeed, that when experiments on the economical efficiency of steam engines are being carried out, much advantage is derived by refilling the boilers, to begin with, with pure fresh *unboiled* spring water naturally aerated. No one has yet carried out the system of feeding air to boilers so fully as Mr. Warsop. At the recent meeting of the British Association at Bradford, Mr. Eaton read a short paper on the Warsop system, the principal features of which we cannot do better than reproduce here, as the statements made bear with precision on the subject matter of this article. The principle of the Warsop system was explained at the Exeter Meeting of the British Association, and certain results obtained in practice were brought before the Institution of Mechanical Engineers in Birmingham, and the substance of that paper has been published in our columns. It will be remembered that it referred to a locomotive, No. 369, on the Lancashire and Yorkshire Railway, which had one feed-pump removed, and replaced by a single acting air-pump; Mr. Eaton's last paper gave a summary of the results obtained with this engine, which we reproduce in the following table, premising that No 38 is a sister engine to No. 369, and that the work done by each engine was as nearly as possible the same.

A. D.	Engines.	Engine miles run.	Coal consumed.		Average lbs per mile.
			Tons.	Cwt.	
1871	In steam. No. 369	21,048	403	6	42.92
1872-3	In steam and air. No. 369	27,934	472	10	37.89
1872-3	In steam. No. 38	28,053	550	10	43.95

Six engines are constantly employed between Normanton and Liverpool, and Mr. Eaton gives the performance of these six engines for six weeks, ending July 3d, 1873, as follows:

Engines.	Diameter of cylinder.	Engine miles run.	Coal consumed.		Average lbs. per mile.
	Inches.		Tons.	Cwt.	
369	15	4477	65	5	32.64
Steam and air.					
38	15	3987	74	0	41.57
Steam.					
379	16	4700	84	15	40.39
381	17	4353	74	15	38.47
383	17	4698	75	15	36.11
391	17	4310	77	5	40.15
Total.....	....	26,525	451	15	.....

According to Mr. Eaton the air was sent into the boiler at an average temperature of 650 deg. As the boiler pressure is not

*This is not strictly accurate, as the formula given above applies only to constant pressures and variable volumes.

stated, we are unable to say what the temperature of the air was as it left the condensing pump. One remarkable feature in the working of the engine was the almost total absence of incrustation.

Balancing all the advantages and disadvantages of the various systems, we arrive at the conclusion that a very considerable economy can be effected—especially in working engines very expansively—by the introduction of air into the water of the boiler on Warsop's system; but the quantity required is only small, and in properly set boilers nothing whatever is to be gained by the use of coils in the flues, except in so far as their presence prevents the air already heated by the air pump from being cooled.

THE RUIN OF THE RIVERS.

From "The Builder."

The pollution of rivers is one of the evils brought about by a century of neglect of public interests, while individuals have been sharp enough to see the opportunity and to penetrate the weak places of public law. So do thieves where there are no policemen. In this way an unpatriotic spirit has been begotten, and selfishness has taken root in the public mind. The natural advantages of the country have almost been turned into a curse to us, for want of regulation and of law and order. We see this every time the subject of river-pollution is broached. Let us see what we can by the light of the report of the Select Committee of the House of Lords on this subject, dated July 21, 1873, which has recently been issued, together with minutes of evidence. It will be remembered that the Rivers Pollution Commission of 1868 proposed in their first report, in 1870, standard degrees of pollution beyond which no refuse liquids ought to be discharged into streams of water of general use. The refuse of manufactures as well as town sewage was embraced in these propositions, and it has been pretended by the manufacturers and others having private interests, antagonistic to those of the public, that the proposed standards would be unattainable.

Dr. Lyon Playfair, a chemist, a manufacturer, and a member of Parliament, says that the standards proposed by the Commissioners are in his opinion not severe enough, although they are expressed in such scientific language as to frighten the manufacturers, who think them more severe than they are in reality, and he has drawn up another set of standards meaning the same thing, but couched in more popular language. These amendments of Dr Playfair were approved by Mr. Stansfeld, the President of the Local Government Board, but he thought it desirable, before embodying them in any Bill to be submitted to Parliament, that they should be submitted to public criticism. We have beforetime given the standards proposed by the Commission, but we repeat them here in juxtaposition with Dr. Playfair's amendments. Liquids exceeding the following degrees of pollution are to be prohibited from discharge into watercourses in the purity of which other persons than the polluters are interested.

Dr. Frankland's Scale.	*Dr. Playfair's Scale.*
3 parts by weight of dry mineral matter in suspension in 100,000 parts by weight of the liquid.	3 grains of mineral matter in suspension in a gallon.
1 part by weight of dry organic matter in suspension in 100,000 parts by weight of the liquid.	2 grains of organic matter in suspension in a gallon.
2 parts by weight of organic carbon in solution in 100,000 parts.	1½ grain of organic carbon in solution in a gallon.
3-10 part by weight of organic nitrogen in solution in 100,000 parts.	2-10 grain of organic nitrogen in a gallon.
A distinct color by daylight when a stratum 1 in. deep is placed in a white porcelain or earthenware vessel.	
1-20 part by weight of metallic arsenic in 100,000 parts by weight of the liquid.	1-10 grain of metallic arsenic in a gallon, either in solution or suspension or in any form of combination.
2 parts by weight of any metal except calcium magnesium, potassium, and sodium, in solution in 100,000 parts by weight of the liquid.	1 grain of metallic copper or lead, in any form of combination, in a gallon.
1 part by weight of free chlorine in 100,000 parts by weight of the liquid after acidification with sulphuric acid.	

Dr. Frankland's Scale.	*Dr. Playfair's Scale.*
1 part by weight of sulphur, in the condition either of sulphurretted hydrogen or of a soluble sulphuret.	1 grain of sulphur, either as sulphuretted hydrogen or as soluble sulphuret, in a gallon.
An acidity greater than is produced by adding 2 parts by weight of real muriatic acid to 1,000 parts by weight of distilled water.	An acidity greater than is produced by adding 100 grains of real muriatic acid to a gallon of distilled water.
An alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1,000 parts by weight of distilled water.	

It is proposed also to prohibit the discharge into any stream, of such manufacturing waste products as will raise, whether in suspension or solution, the foreign matters in the water of the stream to the extent of five grains in the gallon, provided that the water so polluted is not taken for examination from any part of the stream (and in the case of a tidal stream at low tide), at a less distance below the place of discharge than the breadth of the stream opposite to it, and at no greater distance than twice the breadth of the stream at the place of discharge. This last precaution, of prohibiting the discharge into a stream of such refuse as would raise the foreign matters in the stream itself to five grains in the gallon, is an addition of Dr. Playfair's to "catch the stream itself," for the other standards merely catch the drains going into the stream. "I want to catch the stream, and see that the stream itself, as an additional precaution, is not polluted by a number of drains going into it." And as to the precaution of taking the water for examination from within and without certain prescribed distances from the outfall of a drain, as described above, the object is to prevent the sample intended to be analyzed being taken too near the drain's mouth; and so not indicating fairly the state of the bulk of the stream water for some short distance below the point at which the impurity is discharged into it. It appears that it is a practice at many works to discharge during the day very fair waste water into the stream, and then when nobody is watching at night to flush down a great quantity of impurities; but by adopting this additional precaution that practice would be discovered, and the manufacturer held accountable. None of these standards represent perfect purity at all; they only represent a much greater purity than is attained now.

Dr. Lyon Playfair is a director of Young's paraffine oil works at West Calder and at Bathgate, in Scotland, and he confesses to the committee that he is himself a great polluter of streams. But he wants to see the prohibition carried out which affects the pollution from this very manufacture, which is the most difficult of all to grapple with. "I think that if you force us to purify the water which we discharge fouled in this way, before long we shall find efficient modes of doing it. At the present moment we have not efficient modes of doing it, and yet as one of the largest polluters of water in the kingdom from this very thing, I advocate that you should make me purify the water before I discharge it." It is a curious proof of the want of law and order amongst manufacturers, that Government should be appealed to in this manner. One would at first suppose that a director of one of the largest manufacturing works in the kingdom, who should acknowledge that he is himself a great polluter of streams, would put a stop to it at his own works, and we may well suppose he would do so if his were the only case to be dealt with; but he wants a general law to be enacted which shall compel those who are reluctant to assist in the public welfare.

When large quantities of water are required in manufacturing operations, it is usually taken from the stream immediately above the works, and returned to it immediately below them. From the bad state of the law at present, with regard to pollution, any man may have a pure stream fouled by works being built above him, and very often water is sent down fouled to the extent of these standards, or nearly so, and the manufacturer has to commence by a purifying process before he can use the water for his own works. If the law of pollution were rendered general, he would save the enormous amount of reservoir room which he now requires to purify the water which other people have fouled, and which he must purify before he can use it.

Dr. Playfair believes that if the manufacturers were compelled to follow these standards, they would find, as in the Alkali Act, that they would in a very short time exclaim against their being too light, and not against their being too severe; but he thinks that at present, until the manufacturers see that great advantages to themselves will accrue by purifying the

rivers, it is desirable not to be too extreme in the first instance. As to the Alkali Act, which was at first much opposed by the manufacturers, he believes there is not a manufacturer now in the kingdom who does not remove the muriatic acid (one of the chief sources of pollution of the atmosphere formerly from the alkali manufacture) to a greater extent than the Act requires, and who does not find it to his own profit to do so. And he believes it will be the same in the pollution of rivers; it may not always be a direct economy, but it will be an indirect one, giving the manufacturer security that the people below him on the stream will not prosecute him for a nuisance, and that the people above him will be obliged to purify the water before it reaches him.

Dr. Frankland states to the Committee, that, as one of the Rivers Pollution Commission, and having now been engaged in this inquiry for five years, the chief causes of the pollution of rivers in England and Scotland are, first, the casting in of solid rubbish of all kinds. The Commissioners found that the watercourses generally in the kingdom are made use of to carry away worthless stuff, which would be otherwise expensive to get rid of, or to cart away to waste land. This is cast into the stream, and in time of flood is washed down into the lower and stiller reaches, and there it silts up the river, raises the bed, and in many cases causes the flooding of the adjoining lands. The second cause is the discharge of the sewage of towns into rivers. That is a liquid somewhat peculiar, although not differing very essentially from the discharge from some manufactories. Then comes, in the third place, the refuse from manufactories of various kinds, some similar to sewage, others differing from it in their qualities. Fourthly, and lastly, there is mining refuse, which spoils completely for fish, and also for human use, and for agricultural purposes, many rivers in the mining districts. The Commissioners have investigated every river basin where pollution to any considerable extent has already taken place, and they have had abundant evidence that the evil is very great at present, and that it is rapidly increasing both in quantity and in intensity.

In the town of Birmingham at present, General Scott's process (throwing down the solid matters in suspension with quick-lime, and converting the solid residue into cement) is partially applied to the sewage, and the effluent water is discharged into the River Thames; but as the process does not much affect the matters in solution in the sewage water, the river is still highly polluted. It is necessary to take out the matters in solution, either by irrigation or by intermittent filtration through the soil.

With regard to the manufacturers, Dr. Frankland states that the Commissioners have in all cases indicated how each specific form of pollution may be obviated and got rid of in a manner which shall not be unreasonably expensive to the manufacturers, and in most cases not expensive at all, but profitable, he believes. This is an entirely new subject, and it cannot be paid attention to for the next few years without new discoveries in the direction of better purification being made, which would enable a manufacturer at less cost, and, in most cases, at greater profit to himself, and with a smaller amount of plant, to do a greater amount of work in the way of purification. One may reasonably hope for that, says Dr. Frankland, as soon as the attention of manufacturers is directed to purification. "At present, they care nothing about it, but send the water into the stream just to suit their own convenience, without turning their attention at all to this subject of purification."

Mr. J. C. Stevenson, M. P., representing the views of the alkali manufacturers, says, in answer to the question:—

"What is the coloring matter which constitutes the manufacturers' objection to the third test [as given above, it is the fifth]?—A. It is of a brownish color.

Q. Would that be a very poisonous solution?—A. Undiluted, it would be a strong acid solution.

Q. As you pour it into the river, would it be poisonous?—A. In point of fact, it gets so enormously diluted in the river into which we pour it, that no evil comes from it.

Q. It is not diluted, is it, when it passes from the manufactory?—A. No, it is diluted from the volume of the stream."

No comment is needed on such evidence as this to show the enormity of the practice.

One of the objections of the manufacturers is that they ought not to be obliged to employ a patent process in order to comply with the requirements of an Act of Par-

liament, and that seems a very reasonable objection. There are only a few known processes by which the refuse of alkali works can be purified, and they are patented; there are indeed only two in use. Now it would seem that patents for inventions of a character beneficial to the public health ought not to be granted, and yet encouragement of a money value to inventors is necessary. Could there then be any more legitimate object of a Ministry than to encourage these inventions by setting aside a sufficient sum out of the national revenue for this purpose, or to buy up and make free to the public any patent already taken out by any individual at his own expense, the patent being one of recognized value, as those above-mentioned are, on the authority of Dr. Edward Frankland, one of the Rivers Pollution Commission.

Mr. Richard Nickols represents the tanning trade of Leeds, where there are, within the borough, twenty-six large tanyards, employing 2,400 hands. By the by, how suggestive of human machinery, merely, is this word "hands," when used in this sense, and how strongly, though unwittingly, it shows the actual relations that exist between the master and the people who work for him!

Mr. John Botterill represents the dyeing trade, and both these witnesses advise that the refuse should be run into the sewers, and be dealt with by the corporate body, there being no room sufficient for the purpose on the premises of the works; and this view is supported by Dr. Frankland, who says that, in cases where the manufacturers are so situated as to be unable to perform the process of purification themselves, it should be undertaken by the communities in which they live, and that surely some arrangement could be arrived at between the municipality and the individual manufacturer, by which that could be done. The manufacturer might contribute a little more to the rates if needed.

With the exception of galvanizing works, tin plate works, and wire drawing, there are no manufactures carried on in this country from which such portion of the discharges as would be polluting under the suggested standards could not be admitted into the sewers of the town, to be treated at the outfall along with the sewage.

And this witness, having heard all the objections which were stated to the Committee, some of which are given above, says he has heard no objection that he has not repeatedly heard previously from manufacturers; but he thinks there are very few manufacturers in the country who understand what these standards really require them to do; what amount of purification is required. They look upon them as very much more stringent than they are. They are really very lax, and could be complied with in most cases with very great facility.

If the manufacturer *bona fide* desires to prevent pollution, he has no difficulty in complying with these standards; but he has difficulty if he only wants to make believe that he is preventing pollution. There are sometimes, for instance, attached to works, small catch-pits, that pretend to be purifying the liquid from those works; but the liquid flows out of such little catch-pits just in the same condition that it enters them,—it is only a pretence of purification.

Mr. William Crookes, F. R. S., gives his evidence to the effect that he would make the standards "elastic," varying them to suit circumstances; and Dr. Frankland agrees with him so far as that it is desirable that the Local Government Board should have power to exempt, for a certain length of time, at all events, manufacturers who are situa ed, perhaps, in some very unfavorable locality for carrying out the provisions of the Act; but not that elasticity should be given in the standards. He does not see how the standards could be made elastic and effective at the same time.

The minutes of evidence upon which the third report of the Rivers Pollution Commission was based has also recently been issued. The Commissioners addressed questions to the manufacturers and traders which were intended to help them in framing their report, some of which only were answered. One of them was whether the manufacturers had any suggestions to offer as to the best means of avoiding pollution in future, and as to the conservancy of rivers and streams. It is curious to observe the chorus of their answers to these very civil questions. "No suggestions to offer as to the best means of avoiding pollution in future," and "No suggestions to offer as to the conservancy of rivers and streams." And these are the very people who could have offered valuable suggestions on both these questions, and would have done so if they had had any public spirit at all; but selfishness possesses them.

STEEL RAILS IN FRANCE.

From "The Engineer."

The use of steel rails is extending in England, for, notwithstanding the uncertainty of the material, its homogeneity renders it more durable than iron, and the price of steel rails is also now so little removed from that of the very best iron rails, that the adoption of the first by railway companies does not represent much additional expenditure. In France steel rails are daily taking the place of iron rails, and the following particulars of the action of some of the great French lines, will be found interesting. It will be understood, of course, that we content ourselves with putting before our readers the statements of our authorities, without endorsing all their conclusions.

The French Minister of Public Works has sent to the Vienna Exhibition a collection of designs, models, and works relative to the engineering profession, accompanying the same with a volume of explanatory notes, which are divided into sections. To these has been added a treatise published separately, by M. Felix Lucas, ingenieur des Ponts-et-Chaussées, which, in five divisions, discusses the following subjects:—(1) roads and bridges; (2) railways; (3) inland navigation; (4) harbors. Our own especial interest in these matters will, however, confine itself to the second division of Mr. Lucas' work, and we turn, therefore, at once to the statistics furnished by the Eastern Railway Company, with reference to the economical effect of the substitution, on some of the most worn portions of their system, of steel for iron rails, the first-named being supplied to them by the principal French iron works, such as Le Creusot, Terre-Noire, Rive-de-Gier, etc.

The pattern selected for these rails is that known as the Vignolles, and is of the same section as the iron rails weighing 35 kilos. per running metre, or about 74 lbs. per yard, so long used on this line; but their (the steel bars) weight is, from the difference in density between the two metals, nearly 36 kilos. per metre.

In the month of March, 1866, an experiment was commenced by this company with the object of determining the comparative lasting qualities of the two metals, and they laid down in a much-used place, near the crossing at the Villette station, 60 Bessemer steel rails and 60 iron ones, alternating them in groups of 6 rails each. From the time of their being placed on the line until March, 1872, a traffic amounting to 29,000,000 tons dead weight had passed over these metals, with the result that at that date some 31 out of the 60 iron rails were and had been for longer or shorter periods unfit for use, whilst the condition of the other 29 was such as would not justify the estimation of their power of resistance to wear and tear as exceeding a total traffic of 24,000,000 tons dead weight; and it is stated that these last-named bars were of excellent quality. The steel rails, over which a similar traffic had of course passed, were found to have sustained no other alteration than that resulting from an extremely regular wearing down, which was accurately measured by taking impressions in wax of their surfaces, when it was found to correspond to 1 mille. or .039 in. for every 26,000,000 tons carried on those portions of the line where the traffic passed in its normal condition, being naturally more at the places where the brakes were usually applied, though even there the steel rails showed to considerable advantage.

Further experiments were carried out by this company, which have entirely confirmed the results of similar ones on the comparative resistance of iron and steel rails, undertaken by the Northern Railway Company. The following are the figures obtained:—Under flexion, the elasticity of iron rails commenced to change at a pressure of something less than 25 kilos. per square millimetre, and their modulus of elasticity, E, was found equal to 14.3×10^9, the resistance of steel rails up to the limit of their elasticity being equal to 38 kilos.—84 lbs., nearly—or 1½ times that of iron rails, whilst their modulus of elasticity was 18.4×10^9.

Nearly all the iron rails broke under an impact of below 8,250 kilos., whilst those of steel resisted a pressure of 9,500 kilos., With a weight of 300 kilos. falling on a rail at the centre between two points of support 1.10 metres distant from each other, the average height of fall required for the fracture of iron rails was found to be 1.10 metres whilst that for steel bars was more than 4.60 metres; indeed, the greater number of these latter were not broken even

with a fall of 5 metres—the highest obtainable with the apparatus used; and this, although the steel rails experimented on were laid upon a solid cast-iron block weighing some 10,000 kilos., whilst those of iron were supported by a wooden framing fixed on masonry. From these trials M. Lucas has decided that the relative resistance to permanent flexion as between steel and iron rails is, up to the limit of elasticity, equal to 1.5 in favor of the former, whilst their resistance to fracture by violent impact is still higher. The effect of these experiments has been a determination on the part of the Eastern Company to adopt on all its lines a Bessemer steel rail weighing 30 kilos. per metre, in lengths of 6 metres, and this arrangement has been sanctioned by the Government.

The Northern Railway of France has also selected for the whole of its system steel rails of the Vignolles section, weighing 30.300 kilos. per metre, and the first advantage claimed for them is that they wear equally and slowly, whilst under the effect of heavy traffic iron bars rapidly deteriorate, and frequently become unfit for use before they have lost any noticeable part of their weight. The experiments made by this company go to prove that the very best of the iron rails are not equal to a traffic exceeding 20,000,000 tons dead weight, whilst for the inferior qualities these figures should be reduced to 14,000,000 tons. For steel rails, all the trials made show that the wearing of their bearing surface equals only 1 mm. for every 20,000,000 tons carried; and as these bars are manufactured with a view to carrying a traffic of 200,000,000 tons, it follows that their life would be about 10 times that of iron ones, and in this view the substitution of steel for iron represents a very great economy in maintenance, whilst it assures to the permanent way a considerably increased power of resistance, combined with greater security.

The second advantage possessed by these steel rails over those of iron appears from experiments which show that the latter are permanently deflected whenever the compression and tension of the fibres reach from 17 kilos. to 18 kilos. per square millimetre, whilst for steel rails these figures are above 38 kilos.

In the trials by tensile strain the laminæ composing the head of the rail, when made of iron of good quality, offered a resistance to fracture of between 28 kilos. to 36 kilos. per square millimetre, while for those of steel the figures were between 65 kilos. to 75 kilos.; and the main characteristics of steel rails are thus generally summed up—that their actual elasticity and resistance to fracture are at least double those of iron.

With reference to the sections of the rail it is recommended as the practical inference to be drawn from these experiments, that the present height of the iron one weighing 37 kilos., as well as the size and inclination of the fishing plates, and also the convexity of the head—all of which have hitherto given very favorable results—should be retained; and it is also advised that the bearing surface be made as broad as possible, and to this end as much material as may be, should be accumulated in the head by reducing the size and thickness of the foot, provided always that this be not carried to such an extent as to render the rolling difficult, or to cause any marked disproportion between the height of the rail and its base. Theoretically speaking, when most worn, the section of the rail ought to be such that the work on the fibres of the head and foot amount to about the same, but the adoption of such a form would probably lead to a foot, which would be a little too narrow, and too small to find proper support on the sleepers—in the section adopted the compression and extension become equalized when about 5 mm. have been worn away; but the steel rail is even then strong enough for use, and its strength is still superior to an iron one of 37 kilos.

The following tests have been decided upon as those which steel rails ought to bear: First experiment: (1) By pressure. Each rail should sustain between two points of support 1.10 metres apart, the application of 17,000 kilos. during the space of five minutes without any appreciable set remaining after the experiment. (2) A pressure of 30,000 kilos. without a set exceeding 25 mms.

Second experiment: By impact—Each half of a broken rail being placed on two supports distant 1.10 metres between the centres, which latter are fixed on a cast-iron anvil block weighing 10,000 kilos., should support without breaking, the blow of a weight of 300 kilos. falling from a height of 2.25 metres on to the middle point of the bar between the two bearings, the relative deflection at the following different elevations for the fall being—

	Metres.	Metres.	Metres.	Metres.
Heights.....	1.00	1.50	2.00	2.25
	Millimetres.	Millimetres.	Millimetres.	Millimetres.
Deflection.....	1	3½	8	18 to 20

Just at the present moment some experiments are being made on a new system of plate laying, which consists in not placing the joints of the rails of each line on the same sleeper, but to break the joints, by having one on one transverse and the other on a neighboring one. Although this new method has scarcely been a sufficient time in use to enable very accurate judgments to be formed, it is generally considered that it gives an easier movement than when these joints are opposite each other—in effect, that the shocks due to the trains passing over the two joints not being simultaneous—their action on the movement of the carriage is proportionately lesseñed from this very fact. These shocks appear to be further diminished from the following causes:—

(1) The sleeper on which one joint is made being no longer inclined to movement at both ends at one and the same time, is, on the contrary, maintained in its position by the pressure of the opposite rail, which then acts as a continuous support.

(2) The sleeper receiving thus less violent shocks, is better able to resist any thrust.

(3) That in the event of a joint giving way at the passage of one wheel, the carriage, being still supported by three others, cannot easily run off the line.

These last experiments are rather beyond the question of the relative advantages of iron and steel rails; but having them before us at the same time as the others we have given with reference to the comparative value of the two materials, we have not hesitated to place them before our readers as examples of careful and accurate attention to details worthy of imitation. The experience gained on the other French railways from a similar series of observations, are so nearly identical with the above, that we pass them over, and proceed to examine in as few words as may be, what Mr. Barlow said about steel rails in his recent address at Bradford.

Mr. Barlow, looking rather at the possibility of applying steel in far larger quantities than it has been hitherto used to construction, has preferred, and naturally so, confining his observations to what he calls "mild steels," such as are produced in large masses by the "Bessemer," "Siemens-Martin," and other processes, dismissing, as scarcely within the range of adoption in large works, the superior qualities which are only procurable in small quantities, and at high prices. With reference to the toughness and malleability of steel, this gentleman gives an instance which is worth placing in contrast with those we have just offered our readers, as the result of the French experiments. He says that he has seen a piece of steel rail, weighing 80 lbs. per yard and 12 ft. in length, held fast by one end and twisted at the other, until it broke; the fracture occurring near one extremity and leaving about 11 ft. in the twisted form given to it. In this state the rail was laid on two bearings, 3 ft. 6 in. apart, and subjected to the blow of one ton falling 30 ft., and it bore one of these blows without breaking. Such an experiment is a mere *tour de force* of little practical value. Several other steel rails were also tested under a weight of 1 ton falling 20 ft. on a 3 ft. 6 in. bearing, and although not one broke, the effect of the impact was to produce a set of about 2½ in. As a rule, indeed, these bars yielded to the third blow; and although some of the above results are highly favorable to the toughness and malleability of steel, there are yet on record instances of steel rails breaking with the jar produced by being thrown off the delivering wagons on to the ballast. Hence, argues Mr. Barlow, there is a quality of steel manufactured and sold which is cold short, and not reliable for use for engineering purposes. But what are the causes of this apparent uncertainty in the quality of steel? Is it the result of different chemical combinations; of the varied qualities of the ore employed; of the processes pursued by different makers; of the want of precision in the time allotted to the several stages of the manufacture; or the degree of heat employed, any inaccuracy in which a want of proper apportionment thereof to the quality of the iron converted must seriously affect the character of the steel produced? We apprehend that with reference to the chemical combinations doctors have agreed to differ, and we need only, in proof of this, refer to the discussion which ensued on the reading at the last April meeting of the Iron and Steel Institute, of Dr. Siemens' paper "On the Manufacture of Steel by Direct Process," when Mr. Snelus is re-

ported to have said, that if too small a quantity of manganese was used as spiegeleisen, the steel was red short, and would not roll well. He had found also that with ½ per cent. of manganese remaining in the steel the metal was both tough and ductile, and that when the manganese in the steel came down to something like ¼ per cent. the metal was very difficult to roll; and hence he thought the manganese—or spiegeleisen—performed another function in addition to that of removing the oxygen, which was its chief function, and that was as forming a definite alloy with the iron. Mr. Riley, on the other hand, could not agree with Mr. Snelus "as to the manganese being beneficial as an alloy in steel, because it was found that some of the very best steels did not contain more than a trace of manganese; and he had his doubts whether it had that special advantage which Mr. Snelus had attributed to it. Possibly in some descriptions of Bessemer and the lower qualities of steel, it might be of some advantage." Mr. Riley, however, guarded himself, in reply to a question, by stating that his remarks applied more particularly to tool steel; whilst Mr. Williams asserted at the same meeting that he had come to the conclusion "that masses of steel would not roll for making rails except at a very low heat, and, in fact, at such a heat as would keep the material so hard that the machinery would not roll it unless it contained manganese." Here, then, our wise men arrive at no distinct solution of what is the effect of manganese in steel, or what proportion of it, if any, is necessarily present in that metal, or whether it acts as a flux or an alloy.

With reference to other ingredients sometimes present in steel, such as graphite, silicon, sulphur, and phosphorus, we could point out as great differences of opinion amongst steel makers; and regarding the qualities of the ores employed, process pursued, and want of precision in the time allotted to, and degree of heat employed in the manufacture, we incline to the opinion that all these are circumstances constantly varying; that, in fact, no two attempts to convert iron into steel are made under precisely the same conditions in every respect, and hence the different results arising from operations which, to insure equality of produce, should be as accurately carried out as the operations of the laboratory or the dispensing of a chemist. These difficulties about what is steel, and how it is to be manufactured, are fully recognized; they are the curse of the material. Who knows what is the essential difference between steel and what is usually called iron?—we are tempted to ask, without, of course, going into historical questions, whether the secrets possessed by Andrea di Ferrara, or the manufacturer of the Toledo blades, have ever yet been satisfactorily explained. But that there was an especial excellence about their productions, which at the present day cannot be reproduced, is a fact which we think will not be disputed. There is one other portion of Mr. Barlow's address with reference to this uncertainty in the quality of steel that strikes us very forcibly, pointing out that in samples tried by Mr. Kirkaldy the quantity of carbon varied from ⅛ per cent. to nearly 1 per cent., and with this small variation in the carbon the strength ranged from 33 tons to nearly 53 tons per inch; and the ductility represented by the ratio which the fractured area bore to the original section of the bar, varied from $\frac{5}{10}$ ths in the tough qualities, until in the harder samples there was no diminution perceptible. And yet he continues: "All these materials are called steel, and have the same external appearance; but possessing, as they do, such a range of strength and such a variation in ductility, it becomes absolutely essential that there should be some classification or means of knowing the respective qualities among them." Turning, then, to the effects of this uncertainty, he adds: "The want of such a classification casts an air of uncertainty over the whole question of steel, and impedes its application. To this want of knowledge is to be ascribed the circumstance that many professional men regard the material as altogether unreliable; while large consumers of steel, in consequence of the uncertainty of the quality they buy in the market, seek to establish works on their own premises and make their own steel." In this we fully concur, but believe that, whilst there is now a great uncertainty in every way regarding both the quality and strength of steel, it is yet possible to fix on some means definitely classifying it; we venture to suggest that although these matters have already been discussed by the Institution of Civil Engineers, their varied aspects still offer ample room for further investigation by it and similar societies, and, indeed, we do not see why numerous

questions connected with steel, and how it is to be defined and classified, should not be made the subject of a Government inquiry, the results of which would, we doubt not, form most valuable additions to the information so much required on this material by our engineers, mechanics, shipbuilders, electricians, etc. We have had a royal commission on coal, and why not on steel?

THE SEWAGE QUESTION.

From "Engineering."

Hydra-headed, the sewage question is constantly cropping up, and September has been prolific in accounts of the doings and non-doings of those who profess to afford a solution of this difficult question. We are at a loss to ascertain which of two important subjects—this and the coal question—is of the most value to the community at large. On either side much is to be, and has been, said, yet but little done. Our position is, therefore, not that of a judge, but to state all those facts which, having been ascertained carefully, can be placed before our readers for their decision.

In the past month we have had several items of fresh intelligence, either pointing towards improvements of old processes or suggesting new plans. At the meeting of the British Association at Bradford, we find that the treatment of sewage by precipitation methods is declared to be an entire failure. On the other hand, we learn that the Native Guano Company, the patentees of the A B C process, has been favorably reported on at Leeds, and its rival, the Phosphate Sewage Company, has recently issued a circular, in which an absolute confidence in its ultimate results, both manurial and purifying, is asserted.

A new scheme has lately been propagated for draining a large area west of Teddington and partially east (in a direct line towards the Thames), of all the sewage products of the district, proposing, at the cost of some two millions, to convey the sewage of the Thames below Crossness, which is at present the position of outflow for the sewage of so-called South London. Practically we may call this the west outer circle of our present metropolitan sewage arrangements. It will embrace numerous towns, villages, hamlets, etc., which now, more or less, discharge their sewage into the Thames. The difficulty that has to be contended with is one almost entirely of an engineering character. In other words, the "levels" are such that pumping is inevitable, to relieve these districts of the dangerous nuisance to which they are now subjected.

We have frequently urged a combination of all the existing sewage schemes as most probably leading to a solution of the whole sewage question. It is evident, however, that our efforts have been, and are likely to be, in vain. Irrigationists, chemical precipitationists, and the advocates of each form of earth-closet system, still maintain their individual superiority, and expect to defeat all their opponents. As an example of the present position, the following abbreviated reports of each advocate are given as issued in September.

We take, first, the report of the effects of the A B C process at Leeds. In previous issues we have described and criticised the operations of the company at Leeds, Leamington and Crossness. It was shown that the manure produced at Leamington was generally attended with good results when applied to suitable soils. We have before us a report of experiments recently made by a sub-committee of the Streets and Sewerage Committee of Leeds, giving the comparative results that attended the use of various manures applied to parcels of land in the neighborhood of that borough. At their last annual report they expressed themselves as quite satisfied with the effluent water produced by the A B C process. But the manurial question was not settled, and this—as we have on many occasions pointed out—is a most important item in the commercial value of any plan of dealing with raw sewages.

The Leeds authorities took six patches of land, each consisting of half an acre, to make what we may properly designate reliable experiments on the value of the manure produced by their work at Knostrop, where they treat a portion of the Leeds sewage by the A B C process. It appears that they employed six different dressings on an equal number of half-acre patches, namely, of street sweepings, which at Leeds

are pretty good, considering the imperfect scavengering of the borough; of stable manure; of Peruvian guano; of "native manure," which, so far as we can learn, is a mixture of the native guano from the Knostrop Works, incorporated with the midden refuse; "native guano" *pur et simple*—that is, the product of the Knostrop Works; and sewage mud, which may be considered as the natural precipitate of the sewage generally. The pecuniary cost and product of all and each of these experiments, which have been just concluded, were as follows:

Manure Employed.	Cost per Patch for Dressing.	Value of Crop per each Patch.
	£ s. d.	£ s. d.
Street sweepings...	4 3 6	2 13 10
Stable manure	2 8 0	3 1 2
Peruvian guano ...	1 12 10	2 16 7
Native manure	1 11 0	2 6 4
Native guano	1 11 10	2 16 7½
Sewage mud	1 18 10	2 8 0
Totals.....	13 6 10	16 2 6½

It hence follows that £13 was, in round numbers, expended on three acres, to obtain a return of about £16, or about £81 for each £100 of produce.

The results so obtained are somewhat anomalous. The Committee, who have had the management of these trials, and whose impartiality is undoubted, have resolved to make sure on future projects. The advocates of the A B C process maintain that their manure is not a stimulant simply, but that its effects are lasting. We have every reason to believe that there is a foundation for this idea, as our own experiments have verified it. The Committee at Leeds therefore proposed to leave each plot exactly as it is this season, to test the permanent value of each kind of manure they have employed.

It is somewhat remarkable that the native guano destroys indigenous weeds and encourages the growth of grain, and especially of dandelion, while sewage proper destroys the latter, and encourages the growth of a heterogeneous class of weeds. Our experience on this point has been respectively derived from a year's inspection (two seasons) of native guano at Leamington, and sewage at Barking. In regard to the universality of the latter, we lay ourselves under correction, simply stating that by the term "weeds" we mean such products of a grass field as the generality of farmers object to for green food and hay produce. It appears that the experience of the Leeds authorities, in respect to the native guano, agrees with this opinion, and this is the more remarkable on account of the great difference which subsists between the so-called weeds of Warwickshire and of the West Riding of Yorkshire. We have already urged on our readers, in our "Notes on Sewage," the importance of studying the "botanical" conditions of the sewage question. Mr. Hope, the great advocate of irrigation, is well aware of the importance of this point in regard to his model farm.

From these remarks it is evident that neither chemical, botanical, nor physical conditions are to be taken separately as an indication of the value of any special mode of treating sewage, for taking all the results of sewage treatment, with the same chemical elements or compounds present, whether at Croydon, Barking, Rugby, Leamington, Warwick, Leeds, etc., the practical deductions are not uniform. In other words, a general law of produce should follow the presence of a certain amount of nitrogeneous and carbonaceous matter in a given amount of diluent, whether that be water, clay, sand, or any other comparatively inert material. The anomaly thus arising, however, is not inexplicable, for it is evident that, while the same manure may be applied to different soils, or the same soil be treated by different manures, the results must be affected by the varying conditions of the two sets of experiments.

We have already pointed out that the manurial value of any deposits affected by the A B C process depends essentially on the kind of sewage treated. The same remarks hold good in regard to every process employed for the utilization of sewage. We state this to prevent any circumlocution in our further observations.

We next remark on a circular recently issued by the Phosphate Sewage Company, which, as is well known, is the chief rival of the Native Guano Company, excepting, however, the General Sewage Company, working under Dr. Anderson's patent. The distinction between these two processes is easily stated. The Phosphate Company treat a natural phosphate of alumina by means of sulphuric acid, by which they obtain a certain amount of phosphoric acid, phosphate of lime, sulphate of alumina, and

sulphate of lime, the lime salts being produced by the addition of "milk of lime," added while the treated phosphate of alumina is passing into the sewage. In our last volume, on page 46, we gave a full description of the process just referred to, and we also, in that article, drew attention to the difficulties in which the company found itself placed in February last. By the circular recently issued to the shareholders we learn that the company have nearly completed their experiments at Barking, which, to our knowledge, have been in progress over a year. It is a pity that public companies are formed simply to try experiments, when the prospectuses on which they are based usually state that such experiments had long previously insured entire and permanent success.

The Phosphate Company, like others, has had to contend with the difficulty of drying the residual product, which, generally speaking, is very intractable. Numerous sewage-drying machines have been proposed, but we learn that the practical suggestions of Mr. Henry Morgan have solved this difficulty. A public trial, which is shortly to take place at the Barking Works, will afford an opportunity of judging of the amount of success thus stated to have been arrived at. But a peculiar difficulty has been encountered by the company. It was originally formed to work the natural phosphate of alumina obtained from the island of Alto-Vela. The San Domingo authorities, however, ignored the concession which had been granted, and consequently the company's supply of material was stopped. We learn by their circular that they have now on hand about 18,000 tons of the phosphate, worth about £60,000; and that they have taken proceedings in Chancery to recover the sum of £65,000, which had been paid for the now forfeited concession. Failing a further supply from Alto-Vela, they anticipate no difficulty in getting a similar phosphate from other sources.

Next on our list of sewage news is the report of the Sewage Committee of the British Association. We are not surprised that the committee prefer irrigation as the solution, and the only one, of the question. At each of the recent meetings of that body, and of the Social Science Congress, irrigation has been alone considered as effective. For all practical purposes none of the chemical processes yet introduced has shown any results approximating financially and chemically to those obtained by the direct application of sewage to land, as shown in the Barking and Croydon farms. Until it is shown that similar or better results can be obtained by other means, the advocates of irrigation are justified in claiming the nearest approach to success for their plan.

Having visited all the sewage farms in England repeatedly, at the different seasons of the year, we have come to the conclusion that their success is entirely dependent on proper management. In ordinary farming precisely the same results hold good. The chief difficulty to be contended with in establishing a universal system of irrigation will be that of obtaining suitable land in each place where the system is to be adopted. The present success of the existing sewage farms is essentially dependent on the accidental circumstance that such land was readily available in the district in which the sewage was to be employed. The great point is to have both in the surface and subsoil great powers of absorption, so that the water may be rapidly filtered away, leaving the manurial portions of the sewage ready for assimilation by the radicles of the plant. It is evi dent, therefore, that a stiff clay land is utterly unfit for sewage irrigation.

Last in our list of reports is that of Dr. J. Whitmore, the Medical Officer of Health for Marylebone. It will be remembered that only a short time ago the outbreak of typhoid fever in the parish, traced to the use of a certain supply of milk, led to the assertion that cows fed on sewage grass had their milk so affected as to produce such disease. This, however, cannot be associated with the Marylebone epidemic, except so far as the milk was concerned, for the cows supplying this did not touch sewage-grass. Dr. Whitmore then states how he traced the evil to one farm. The company from which the milk was obtained possesses eight farms. Dr. Whitmore, with Dr. Corfield and Mr. Chambers Morton, visited these, and seven were pronounced as generally satisfactory. "At the eighth farm, however, the condition of things which then existed (middle of August), coupled with some antecedent facts which had come to our knowledge, demonstrated beyond the possibility of any reasonable doubt that the fountain and origin of the epidemic had been at last found out. The farm, known

as Chilton Grove Farm, is situated some few miles from Thame, in Oxfordshire." Having examined into the cause of death of persons resident on the farm, and traced it to typhoid fever, Dr. Whitmore remarks: "The farmhouse and buildings are placed on a slope, the privy, which is a mere open pit, being placed at the highest point, and the lowest, the well." They discovered that the leakage from the privy had little to obstruct it in its passage to the latter, and this impurity was still further increased by adjacent manure heaps and pig-styes. The cans used to hold the milk were daily washed with this water, and Dr. Whitmore considers that a small portion of the liquid being left in the cans was sufficient to infect the milk afterwards sent away in them. The supply from the farm was instantly stopped, and one cause of the Marylebone epidemic was as quickly removed.

We forbear to make any further observation on the reports of which we have given a *resumé*. Our object is to place before our readers the latest phases of the sewage question. It will be seen that the present situation is eminently one of difficulty, requiring all the aid that science and daily experience can give to so important a subject.

THE MANUFACTURE OF WHITE LEAD, AND THE SANKEY WHITE LEAD COMPANY'S PROCESS.

From "The Engineer."

In Dr. Watson's chemical essays, published at the end of the last century, there is the following short description of the then old process of making white lead:—

"White lead, or ceruse, is lead corroded by vinegar. Thin plates of lead are rolled up in a spiral form, and placed in earthen pots containing vinegar. These pots being ranged on proper stages, and their mouths being covered in such a manner as to permit the vapor of the vinegar to escape, and at the same time, to prevent any impurity from falling into them, a quantity of horse dung is thrown in amongst them; by the heat of which as it grows putrid the vinegar is raised in vapor, and this vapor attaching itself to both sides of every spiral of the lead, which is so placed as not to touch the vinegar, it corrodes the lead into white scales, which, being beat off from the plates, washed, and ground in a mill, constitutes the white lead of the shops."

If we inquire what improvements have been made since this account was written, we shall find the only considerable change has been in the substitution of tanners' spent bark instead of the horse litter. The vinegar or alegar, as the product of soured malt-extract was called, has also been replaced by pyroligneous acid more or less refined. Except minor details of manufacture, nothing more has been introduced to alter the mode of producing ceruse or white lead by this Dutch process. Numerous attempts, however, have been made, and many patents have been secured, to make the article by a shorter method, but practically none have reached a permanent success. It is well known that the particular quality for which white lead made by the Dutch process is renowned is what is technically called "body." The slow corrosion of metallic lead, in which we have at first oxidation, then formation of lead acetate, and then, without actual solution of this salt, the conversion into carbonate, when carried out under favorable conditions of fermentation of the tan, produce a solid, hard mass of white lead, which requires some considerable power to grind under millstones. When thus finely ground and levigated, 1 cwt. of white lead will only take up about 10 lbs. of oil to give it the consistence which is found convenient for packing into casks for paint. The Clichy process, which may be taken as a type of all the precipitating methods, consists in dissolving litharge in acetic acid until a basic acetate is produced, which is then submitted to a current of carbonic acid. The carbonate is, in this case, formed from solution, and is easily obtained of a beautiful white color, and, of course, as an extremely fine powder. The valuable quality of body, however, is sacrificed, and 1 cwt. of precipitated lead will take up 20 lbs. of oil; and though it may be recommended by the salesman as covering a large extent of surface, the covering has not the opacity of the lead made by the older process, and the practical painter declines to go over the ground three times,

when, with another article, two coats will suffice.

For some time the Sankey White Lead Company have successfully worked a patent granted to Mr. E. Milner, by which the conditions for obtaining a pure white lead with the desirable quality of "good body" are arrived at by ingenious but simple means. The ordinary common lead of commerce is first converted into flake litharge in the usual way. The litharge is finely ground and levigated, then mixed with a certain amount of salt, with which it is churned for a short time. An extraordinary change is rapidly set up in the litharge pulp whereby an oxychloride is formed, and the mass assumes a white appearance, and exhibits a strong alkaline reaction. No actual solution of the litharge takes place, and in this respect the process agrees with the formation of the lead acetate in the Dutch process. After a short time the pulp is run into the carbonating vessel, where a current of carbonic acid is passed through the mass at a moderate pressure, until the whole charge is converted into carbonate of lead. The white lead is then collected in filtering vats, washed in the usual manner, and on the authority of Mr. Wm. Baker, who has had large experience in the management of white lead works, it cannot be distinguished from that made by the Dutch process. The following is an analysis of an ordinary sample of the Sankey White Lead Company's product:—Oxide of lead, 83.76; carbonic acid, 15.06; combined water, 1.18= 100.00. Here, then, undoubtedly, at last a successful method has been perfected, which in the detail of manufacture compares most favorably with the older process. The difficulty of obtaining a lead sufficiently pure for white lead purposes has been long felt and acknowledged. The cost of refining even the better qualities of market leads for the older process is done away with, and any of the common brands may now be utilized.

It is now well known how prejudicial to color are small quantities of copper and antimony, and even smaller quantities of silver, in the corrosion of lead. The trial of a new brand of lead must be made with extreme caution, and the result waited for at least two months. The saving of capital buried for this space of time is of course one of the chief features of the new process. Again the accidents of temperature and the state of the bark bring about uncertainty of quality, whilst the lead returned uncorroded is a constant charge on the old process. Manufacturers will be glad to welcome a mode of work which withdraws the workmen to a very great extent from the dangerous contact of the poisonous material unavoidable in the Dutch process, for they only know the cost in loss of time and medical attendance which this entails. It is to be expected that the Sankey White Lead Company will not fail in having the advantages of their process very generally recognized.

REPORTS OF ENGINEERS' SOCIETIES.

THE AMERICAN INSTITUTE OF MINING ENGINEERS.—The American Institute of Mining Engineers held a meeting on the 22d and 23d of October, at Easton, Pa. Among the papers presented were the following: A process for disentegrating or subdividing iron; mode of subdividing, and special use of subdivided blast furnace slag; blast furnace slag cement; manufacture of compressed stone-bricks, all by Mr. Bodmer of England; the system best adapted to work thick coal seams, by Oswald J. Heinrich of Virginia; tests of steel, by A. L. Holley, Esq., of New York.

NORTH STAFFORDSHIRE INSTITUTE OF MINING AND MECHANICAL ENGINEERS.—Mr. Haines, the Secretary, showed a model of a "Permanent Travelling Fence," which has been invented by Mr. Wm. Blakemore, of Wolverhampton, with a view of preventing persons accidentally falling down pit shafts. To the runner which covers the pit top when the tub or cage rests upon it, is attached the fence, and as the runner is removed, to admit of the lowering and winding up of the tub, the fence is easily slided round the shaft, and effectually protects those engaged on the pit bank from accidentally falling down the shaft. Mr. Homer said it appeared to be a very good arrangement, and was very simple, which it ought to be, for any complicated arrangements ought to be avoided. A vote of thanks was unanimously accorded to Mr. Blakemore for having kindly sent the model to be shown to the members.

Mr. J. Ashworth, of Bank Top Colliery, Burslem, then introduced and explained the principle of a rock and coal perforator (Macdermott's Patent) which is adapted for colliery, mine, tunnel, and quarry work. It consists of two metal bars set in the form of a St. Andrew's Cross, and jointed at their intersection; the upper extremities of the cross being connected by means of a screw and nut set in a tube, and the lower ends roughened at the edges and steel pointed. There is also a third hanging leg of variable length, to take the back thrust of the screw. The tube at the top of the standard carries the box and boring mechanism, but set horizontally, and it is also provided with an arrangement for turning the nut on the screw. The mode of operating is so simple as not to require skilled labor, and one man can with the perforator do the work of three or four men boring in the

usual way. It will bore a hole equally well in any direction, and the holes by it are straight and clean. Mr. Homer said he had sent two bailiffs to see one of the perforators work, and he had determined to order some to be used in his pits at once. He thought that anything which they could introduce which would save labor would be a step in the right direction. Hand labor was so difficult to obtain, that if they could get anything in the shape of mechanism to do the work of coal getting, it would be better for all.

IRON AND STEEL NOTES.

SWEDISH IRON.—The report published by the Swedish Board of Trade of the export of iron up to the end of August, shows a considerable decline, as compared with the same period of 1872. The following is a comparative statement of the two years:

	1873. Tons.		1872. Tons.
Pig Iron	39,400	....	49,900
Bar Iron	57,500	....	79,700
Rods	13,700	....	13,000
Blooms	5,900	....	7,700
Total	116,500		150,300

This falling off is the more remarkable, as the high prices must have stimulated production, and the explanation is doubtless to be found in the fact that all the available stocks at the principal shipping ports had already been disposed of during the preceding year.—*Iron Age.*

WELDING IRON AND STEEL.—There has of late been considerable discussion upon the subject of iron and steel, and we think, according to the best information that can be obtained, no one ever had better opportunity for testing the relative properties of steel and iron than Sir William Armstrong, with the kingdom of Great Britain to back him.

Sir William says: "It is impossible that I can hold any other opinion than that the vibratory action attending accessive concussion is more dangerous to steel than to iron," and we think that years of experience in the manipulation of iron and steel fully atttests the correctness of his opinion.

What we desire to impress upon the public mind is the importance of the *two metals combined* for such purposes, and in such proportions as are best adapted for the uses they may be intended for; and, further, to give a few facts in the working of steel by our process which we think of great utility, and which, so far as we know, has never been accomplished by any other process.

We contend that steel cannot be made to answer the purposes of steel and iron at one and the same time; that is, in fact it must be either steel or iron; hence, high grades and low grades of steel, as they are termed, and the lower grades but little, if any, better than the best grades of iron.

It has been said that no one could tell where iron leaves off and steel begins, but we think steel commences where iron presents carbon, and steel is no longer steel when it has lost its carbon, for it is carbon that makes steel.

At a recent convention of the American Railway Master Mechanics' Association, held at Baltimore, it was contended that steel axles did not wear as long as iron. The reason is obvious. No engineer would think of using a car axle made of *steel proper*—that is, of steel high in carbon, which would give the necessary wearing property, but must have steel that will stand the axle test of iron; consequently, it is but iron, or a very low grade of steel, which, for wearing purposes, is no better than iron.

A similar difficulty arises in the manufacture of railroad rails. Steel that is best adapted to wearing purposes is liable to sudden fracture, and would not be considered safe "under accessive concussive strain," quoting a well known author; therefore, the Bessemer steel rail has but the slightest amount of carbon, or barely enough to distinguish it from iron.

We claim that we have a process that will make safe and reliable high grades of steel under any and all circumstances, giving longer life to rails and axles, and safe and reliable as the best iron, by combining iron and steel together.

It is a well known fact that ingot steel is more or less open, porous or spongy, and that no amount of blooming or hammering unites or welds the particles, from the fact that a welding heat cannot be taken upon the ingot after leaving the mould. By our process we can safely bring an ingot to a welding heat, and finish it into a bar at the same heat, without in the least detracting from the quality of steel.—*Iron Age.*

RAILWAY NOTES.

CONTINUOUS BRAKES ON THE MIDLAND AND OTHER RAILWAYS.—We are glad to notice that the painful attention excited by the recent continuous series of more or less fatal railway accidents, enforced as it has been by the energetic comments and strictures of the press, technical and general, daily and weekly, is beginning to bear fruit; and that in consequence, the minds of railway directors and officials, engineers and locomotive superintendents, are opening to a consciousness that if they would continue to keep up to the level of public sentiment, and stand well in public opinion, they must make something more than mere tentative efforts to obtain effective train-control. It is only the other day that an express-train ran into a goods-train on the North British Railway, with fatal results, though the engine-driver could see the obstruction 500 yards ahead, but could not pull up in time; and people ask themselves seriously why these things should be, when, as is well known—or should at least be well known—there is more than one invention, for giving thorough control by continuous brake-power, whereby the express-train could have been brought to a rest within half that distance.

It is all very well for leading daily journals—who, in matters mechanical, don't know a piston from a pinion—forgetful of the old adage, that there are more ways than hanging of killing a dog, to pin their faith upon a single method or invention, for temporary and inscrutable reasons, regardless whether it be or not the best, and placidly to ignore all other competitors, however good they may be; consigning to the waste-paper

basket all communications which might tend to expose their fallacy and enlighten the public. But haply there are more Richmonds in the field than one, thanks to the printers; and, *grâce aux inventeurs*, there are also more continuous brakes than one. We were greatly amused about a week ago at reading a paragraph in a leading daily contemporary, under the heading "Railway Brakes," which contained a thrilling narrative extracted from an American paper, and sent by a "correspondent" as being of interest now in illustrating the utility of "air brakes;" it appears that the engine-driver of a fast train, on the Hudson River Railroad, came in sight of the wreck of a truck (from a preceding accident) at a distance of about a quarter of a mile (440 yards); the engine was reversed, and the fireman ran back and "pulled the patents," which held spendidly, so that the collision, when it came, as come it did, was only very slight. Now this is very poor testimony indeed to the value of Continuous brakes to begin with; and, moreover, as a matter of fact, the "patents" in question were not "air brakes" at all, but Cremer's patent brake, a very different thing; which is a mere safety brake, operated by springs, kept in continual action, and only released for a case of emergency by pulling a cord; the hand brakes being used for ordinary purposes.

We have in preceding articles given a description of the pneumatic, air, or Westinghouse brake, as used on many American lines; and also of Barker's Hydraulic Brake, and Chapin's Electric Brake, as adopted experimentally on British railways, which, for efficiency, cannot be surpassed.

It would seem—and we are glad to record—that these continuous brakes are passing rapidly beyond the experimental stage; and we learn that the Midland Railway, in particular, under Mr. Allport's vigorous management, is giving evidence of great and praiseworthy enterprise. They are now fitting up no less than four trains and fourteen "Pullman's" cars, provided with the electric continuous brake of Mr. W. B. Chapin. Most of our readers, even those who have not graduated in American railway-locomotion, will be familiar with the famous American sleeping-cars, for long journeys, comprising every convenience, which go by the name of their inventor, Mr. Pullman. The Midland Railway Company will, we believe, be the first to introduce them on a large and practical scale in this country; and these fine carriages, besides being provided with the electric brake, are fitted up with what is known as the Miller platform, and Allen wheels. These wheels are made of compressed paper sheathed with wrought-iron plates and hooped with crucible steel tires, made and supplied by the famous Krupp, of Essen, at £20 each, specially for Mr. Pullman's cars. We recently gave a brief account of the Allen wheel, for which Mr. W. B. Chapin, 32 Lombard street, London, E. C., is the sole agent in this country, and we shall shortly give fuller details of the same.

But it is not only on the Midland line that continuous brakes are being adopted; we learn that trains are being fitted up with the electric brake on the South Eastern and North British lines, in this country, all the fittings being made for Mr. Chapin by the firm of Stacey, Davis, & Co., Derby, and supplied, for each carriage individually and complete, to the companies.

Complete sets of electric continuous brake fittings are also being sent out for trains on various foreign lines of railway; among others to the lines of the Societe Generale des Chemins de Fer, in Russia; the Chemin de Fer de l'Est, in France; the Austrian Nordbalm (Director von Crichlaer); Carl Pill's Norwegian narrow gauge line; also to lines in Central America, for Mr. Keith; and to Messrs. Miggs, chief engineers and Government contractors in Peru, and for lines on the West Coast of South America.

Thus we may hope, and confidently look forward to the time as being near at hand, that thorough train control will be secured upon every railway by the adoption of efficient continuous railway brakes, of one kind or another, upon every train, passenger, goods, or mineral.—*Iron.*

RAILWAY ACCIDENTS.—The following frightful record we copy from the columns of "The Railroad Gazette."

For the twelve months ending with August our record stands as follows:

Month.	Accidents.	Killed.	Injured.
September, 1872.....	71	24	104
October.....	90	29	102
November.....	103	37	114
December.....	112	42	133
January, 1873.....	178	40	199
February.....	133	25	126
March.....	112	18	92
April.....	101	23	88
May.....	79	10	113
June.....	90	12	104
July.....	90	18	80
August.....	150	63	155
Totals.....	1,509	341	1,410

In this we have made a correction in the July report published last month, which reduces the number of injured by 39, there having been reported 42 hurt by an accident in Minnesota by which only three were injured.

Last year (when our report was exceptionally imperfect, however), we reported for August 63 accidents, by which 15 were killed and 49 injured.

The report this year shows a shockingly great and unaccountable number of accidents, many of which were exceptionally serious. The freshets of the month might account for some increase, especially in the slighter accidents, and probably the great accidents attracted so general attention to the subject that such casualties were more fully reported in the newspapers; but this cannot account for the enormous number, which was exceeded only in the month of January, when half the railroads in the country were running on snow. And an examination of the several cases indicate that no natural cause special to the time had anything to do with the greatest portion of them, and especially the more serious ones, but there seems to have been an epidemic of disorder and disobedience. Several of the severest were the direct fruit of a clear disobedience of orders, and in three cases train men were recommended for indictment for criminal negligence, while in

one they were actually indicted. A severer discipline seems to be the great lesson taught by the frightful record of the month.

The average number of accidents per day, according to our reports since the beginning of the current year, has been: January, 5.74; February, 4.75; March, 3.61; April, 3.37; May, 2.55; June, 3.00; July, 2.90; August, 4.84; for the eight months, 3.43.

The railroads in most parts of the country are now having or beginning to have their heaviest traffic, and crowding of roads increases danger, while the increase in the number of trains of course multiply the individuals which are subject to accident.

PRALL'S PUMP.—Mr. W. E. Prall, of Washington, has supplemented his invention—brought out last year—of an apparatus for supplying tenders of locomotive engines with water, by improvements intended to obviate all risk of obstruction by foreign substances, causing the apparatus to become inoperative. Mr. Prall's original invention, now pretty generally known, depends upon the automatic action of a valve in a water tank, unprovided, however, by any appliances whereby the valve can be adjusted, or its automatic action affected by the lodgment of any foreign substance; a defect which it is the object of the present improvement to remove, while retaining the perfect automatic action. The valve used is either a clack, hinge, or spindle valve, in combination wherewith is arranged a lever pivoted to the walls of the tank, or on any other suitable and convenient support; and connected with a rod extending upwards with a handle above the reservoir, in some position convenient for manipulation. For the purpose of maintaining the submerged tank in its position at the bottom of the reservoir, even when the water is entirely expelled therefrom, the eduction pipe is made to act as a stay, or special braces are affixed from the walls of the reservoir to the tank. For the attachment between the air-reservoir pipe and the water-reservoir pipe, the coupling consists of a male part, with a collar on one end, provided with grooves to permit the passage of two hooks on the female part of the coupling.

ENGINEERING STRUCTURES.

THE GREAT BRIDGE AT LOUISIANA, MO.—A writer in the Louisiana (Mo.) "Press," of recent date, thus describes the great bridge now in course of construction at that point:

Starting from this side, we first encountered a number of men at work with the steam pile saw, cutting off piles below the surface of the water, for the foundation of the first, or shore pier. This consisted of a circular saw fixed on the end of an upright shaft and run by a steam engine. The frame work was moved along from pile to pile and so regulated as to cut them off on a level. In this manner the foundations for the piers are constructed. The piles are first driven into the bed of the river with a hammer weighing 3,200 lbs., worked by steam engines, and these piles are evenly sawed off in the manner described. The caissons are launched and they float immediately over the foundation prepared for their reception, until the weight of the masonry sinks them to their places. The caissons are constructed of heavy pine and oak timbers. A strong platform of square oak timber is first made from two to six courses in thickness: then two courses of pine plank are overlaid, the top course being jointed and tightly caulked. The sides and ends are attached and held together by means of iron bolts and dogs, and after a thorough caulking, a large water-tight box is thus secured for the building of the piers. The derricks are next brought into requisition, and the dimension stone is lifted from the flat boat and placed by the masons in the caissons. The increasing weight of the pier as it goes up, gradually sinks the caisson until it rests securely on its foundation. The diver is then called upon to make the above described platform or bottom of caisson secure to the pile foundation, which is done with heavy iron drift bolts. The sides and ends, however, are taken off and used again on other occasions. Thus the piers are constructed.

The next place visited was the pivot pier, and that mass of solid stone work is the principal feature of the entire substructure. It is a model of masonry and bridge architecture. It is almost round, with a diameter of 42 ft. at the base and 40 ft. at the top. It contains 1,200 cubic yards of solid stone—all put up in the incredibly short space of 12 days.

It is underlaid with 120,000, board measure, ft. of square timber; 15,000 lbs. drift bolts were used in its construction, and the whole "structure of majestic frame" rests on 200 piles. Two rest piers, each 200 ft. from pivot pier, built of oak and filled with riprap, will support the end of the draw when turned for the passage of boats. A break crib, made of oak, filled with stone and sheathed with iron, will be placed above the upper rest pier. Two floats, each 200 ft. long, built of wood and iron, whose ends are made to fit into grooves in the corners of the pivot pier, and respective corners of the corresponding rest piers, are to be constructed so as to rise and fall with the water. These serve for a protection of the main pier to keep out boats, rafts and heavy drift wood. Eleven smaller piers will complete the points of support on which the bridge will rest, and of which four are already completed. There will be eleven spans of the following length: Two draw spans, each 200 ft. in clear; one raft span, 250 ft; one 200 ft., and seven others 160 ft. each. The superstructure will be of iron, and is to be built by the Kellogg Bridge Company, of Buffalo, N. Y., and the Keystone Bridge Company, of Pittsburg, Pa.

In connection with the bridge are the east and west approaches, the latter having a bridge over Noix creek 120 ft. span, built on stone abutments. This approach extends 500 ft. into the river, constructed of heavy embankments and strong riprap walls, while the east approach is built out 1,200 ft. in the river with similar embankments.

On the bridge proper 5,000 cubic yards of first class masonry, 45,000 cubic yards of riprap, 180,000 yards of earth in embankment and 5,000 piles will be used in the substructure. All the masonry rests on timber foundations sunk 4 ft. below lowest water ever known. A large lot of machinery has been in constant use on the works, among which may be enumerated: 3 pile

drivers run by steam engines: 3 derricks for laying piers, also operated by steam engines, and one by horse power; 8 hand derricks used on shore for handling stone, loading boats, etc.; 20 flat boats for handling dimension stone, riprap, piles and timber; a divers' boat, apparatus and crew, for work under water, and a steam boat for towing.

The cost of the substructure in the aggregate will amount to nearly $300,000. At the present rate of work the whole bridge will be ready for the crossing of trains by the 25th of December. *Iron Age.*

MODERN TUNNELLING.—In the Economy and Statistics Department of the British Association, Mr. C. Bergeron Lausanne, Switzerland) gave a description of the works connected with the St. Gothard Tunnel, the contractors for which are under heavy penalties to complete it in nine years, and which will be more than 2 miles longer than the Mont Cenis Tunnel. The drills used were those of Messrs. Dubois and Francois, and were made at Seraing. These machines were worked with compressed air at 5 atmospheres. Dynamite was used for blasting, but the process was very slow. He had heard that the Americans were going to construct a tunnel 11 miles in length in five years, and he supposed they would use some more improved means. He had seen machines for boring holes 3 or 4 ft. in diameter, the blows being struck with a force of 8 or 10 tons. He thought that probably some adaptation of the steam hammer, mounted on trunnions like a cannon, would be invented, which would smash the rocks and supersede blasting entirely. Sir John Hawkshaw said the subject of cutting or boring through rock was one of great importance at this moment, because the age was apparently going to be one of long tunnels—tunnels which, until recently, were never dreamed of. The author of the paper had spoken of hammering machines, but at present he could not see any other way of cutting except by boring by such a machine as that which was brought under the section on Monday—Burleigh's boring machine, which he had inspected that morning, and which seemed an admirable machine for boring hard rock. Of course this system necessitated blasting, and the great evils connected with it. He was inclined to think, however, that with a little more care and attention in cutting round the circumference, some of the evils of blasting might be avoided, although there would always be danger and difficulty. The system mentioned by the author of the paper seemed to him not only too expensive, but going back to brute force, and not depending upon mechanical skill.—*Railroad Gazette.*

ORDNANCE AND NAVAL.

THE GERMAN NAVY.—According to the Navy list of the German empire, which has just been issued, Germany possesses, besides ten unarmed steamers and eight unarmed sailing vessels, eleven ironclads, one line of battle ship, five first and eight second-class corvettes, four advice boats, one yacht, nineteen gunboats, two transport steamers, two sailing frigates, and three sailing brigs—altogether fifty-six ships, fifty of which number are armed with 378 guns. These numbers look very well on paper, but in reality they are reduced considerably if the vessels still building and those of no use in war are subtracted. Five ironclads and three corvettes of the second class are still building, and most of the remaining vessels, especially the sailing ships and the gunboats of older construction, are useless for war. It will, nevertheless, be interesting to learn the names, etc., of those vessels which will form the nucleus of their future navy. These are:—

Names.	No. of guns.	Measurement in English tons.	Displacement in English tons.	Horse-power indicated.	No. of men.
Koenig Wilhelm	23	5939	9603	8000	700
Kaiser	9	4586	7559	8000	...
Deutschland	9	4586	7559	8000	...
Friedrich Carl	16	4003	5912	3500	500
Kronprinz	16	3404	5480	4800	500
Grosse Kurfuerst	6	4118	6663	5400	...
Koenig Friedrich der Grosse	6	4118	6663	5400	...
Borussia	6	4118	6663	5400	...
Hansa	8	2372	3553	3000	...
Arminius	4	1230	1583	1200	130
Prinz Adalbert	3	779	1479	1200	130

The list shows that to man the ships already completed 7,833 men are required, which number will be raised to upwards of 11,000 after the completion of the ships now building.

THE GERMAN "INFANT."—The German 700-lbs. "Infant," which is 30½ centimetres in diameter, has, according to the "Borsen Zeitung," of Berlin, "already fired 230 shots, 5 of them with the maximum charge of 130 lbs., without sustaining the slightest injury, either to the barrel or the carriage, while the new English 600 (? 700) pounder, the 'Woolwich Infant,' which is thought so much of in England, was strained in the barrel after the fourth shot." Though 230 discharges are very few in comparison with the requirements of war, yet it is noteworthy that no English gun of similar calibre has sustained anything like this number of rounds, and that the German "Infant" has gone through this ordeal "without sustaining the slightest injury to the barrel," whereas the "Woolwich Infant" had "the driving edges of the grooves slightly worn," and local scoring begun after only 6 rounds from the 11.6-in. bore. After 35 discharges, the erosions, enlargements, and groove marks were removed by boring the "Woolwich Infant" up to a 12-in. barrel; but at the 12th round the renewed barrel showed enlargements where the rear studs come first into driving bearing, at the 33d round 4 grooves were found cracked at the same spot, and at the 38th round the "Infant" was found *hors de combat* from an accumulation of injuries at the point where the rear stud comes into driving bearing. Contrasted with this limited endurance, the Germans have some right to crow over "The 'Woolwich Infant,' which is thought so much of in England," seeing that their 700-pounder "Infant" "has already fired 230

shots, 5 of them with the maximum charge of 130 lbs., without sustaining the slightest injury to the barrel." The second "Woolwich Infant" has been returned from Shoeburyness to the Royal Gun Factories, without firing even so many heavy charges as its precursor, and is not likely to be allowed to be injured by rapid discharges, even if it fire any more projectiles with heavy charges at all. It is also noteworthy that, whereas the "Woolwich Infant" is reduced to a maximum charge of 110 lbs. P. powder, the German "Infant" consumes 130 lbs. powder. We are not told by the "Borsen Zeitung' what initial velocity is produced by this 130 lbs. charge, but if the increment of velocity be at all proportioned to the increase of charge, the battering power must be greatly in excess of our "Infant," though inferior to that of the French "Infant,' which consumes 137 lbs. of powder behind an 820-lb. shot. Thus the rifling system, which "has decidedly the lowest velocities," with similar charges, has necessarily decidedly the smallest maximum powder charges, and consequently "decidedly the least penetration."

BOOK NOTICES.

THE GALVANOMETER AND ITS USES: A MANUAL FOR ELECTRICIANS AND STUDENTS. By C. H. HASKINS. New York: D. Van Nostrand, 23 Murray street. 1873.

The distinguishing characteristic of the electric and telegraphic literature of the past few years is its eminently practical character. Although the telegraph has been in commercial use in England since 1839, and in America since 1844, yet the large number of operators engaged in its service were, for a quarter of a century, almost entirely dependent upon verbal and empirical instruction for such technical knowledge as they were able to acquire. It is true there was no especial lack of books on the telegraph, both of a historical and a popular character. Many of these were of great interest and value, and not by any means destitute of scientific information, but yet the average operator might have searched in vain through the pages of Lardner, Jones, Turnbull, Schaffner and Prescott for instruction which would enable him to set up the simplest way office on a telegraph line, with its local battery, switch, lightning arrester, etc., properly arranged for service, to say nothing of the mysteries of repeaters, combination locals, and other more or less complicated arrangements, which it is now incumbent upon every good operator to understand. Even such a simple and every-day operation as that of testing for the location of a cross, might have forever remained an enigma to the ordinary operator, so far as he depended upon books for his enlightenment. We can all remember how it was a dozen years ago. There were one or two persons in every large telegraph office who had a local and sometimes a national reputation as "great electricians." They were especially "great" on "connections," and their sagacity and success in "hunting trouble" used to be regarded by the rank and file as something little less than superhuman. Those men had acquired their really superior practical knowledge by long and careful observation and experiment, with no guide but their individual intelligence and common sense. Their theories were crude and erroneous, and often calculated to excite the smile of the more highly educated telegrapher of to-day; but when we consider their limited opportunities for sound scientific instruction, and the many difficulties they were obliged to contend with, of which the operator of to-day has no conception, their practical success as operators, managers and superintendents, is certainly little short of wonderful. It is hardly fair to blame those men if they sometimes chose to keep their knowledge to themselves as much as possible, after all the labor and time spent in accumulating it, nor if they at first looked with disapprobation and even dismay upon the new order of things, when the most ordinary "plug" might, if he chose, learn to run wires and set up repeaters as correctly as the chief operator himself.

The publication of Mr. Culley's "Handbook of Practical Telegraphy" in England, and of Mr. Pope's "Modern Practice" in this country, marked the commencement of a new era in telegraphic literature. The laws of electrical science, hitherto considered so abstruse and difficult, were explained in a concise and easily understood manner, and their practical application to the every-day work of the telegraph office exemplified. Both these treatises were in many respects incomplete and defective, but their positive merits far outweighed their shortcomings. That they supplied an acknowledged want is shown by the fact that their circulation has been actually enormous, in proportion to the number of persons engaged in telegraphic pursuits in the two countries.

When Pope's "Modern Practice" was first published, now less than five years ago, the system of testing telegraph lines and apparatus by actual measurement was almost utterly unknown to the practical telegraphers of America. There were probably not a dozen persons in the service who had any intelligible idea of the process, either in theory or practice, and these few were generally looked upon as "visionary theorists," who would bear watching pretty closely. Since that time knowledge of this kind has been rapidly and universally diffused, by the circulation of a practical class of books, and, perhaps, in a still greater degree, by the able contributions of such men as Farmer, Brooks, Pope, Haskins, and others in the "Telegrapher"—the value of which to the telegraphic interest of the country has been simply incalculable.

In the present work Mr. Haskins—who needs no introduction to our readers—has given us a book that every working electrician, both here and abroad, will be very grateful for. Here are all the necessary tables and formulæ; everything required for every imaginable test, conveniently and compactly arranged, and put up in a form which can be carried in the pocket, so as to be ready for use at all times, and at a moment's notice. The idea is a good one, and worthy of the strong common sense of the author. We are pleased to see that it has been equally well carried out.

Mr. Haskins says, in the first place, that, "To enable the student to work understandingly in galvanometrical measurements, it is necessary that he should comprehend the laws on which such measurements are based." Accordingly, he gives in the "explanatory chapter" a condensed,

thorough, plain and easily understood summary, embracing the laws regulating the flow of the current, resistance, electro-motive force, units of measurement, etc., in accordance with the most generally received modern theories. This chapter is well adapted to the comprehension of the average telegrapher, and ought to enable him to attain a satisfactory knowledge of the subject. We must, however, take exception to one statement on pages 13 and 14, or at least to the manner in which it is presented. The author says: "In all cases the expenditure or consumption of material in a battery is in exact proportion to the work done, that is to the current evolved; therefore, the expenditure of battery material with three lines to a battery is three times that of one line to the same battery, and there is no economy in working several lines from one battery except in room occupied."

Mr. Haskins' premises are correct, but his conclusion is otherwise. If we practically obtained in the exterior circuit the whole force generated by the consumption of material in the battery, the statement would be true, but such is unfortunately not the case. The loss from "local action," so called, in some forms of battery—such, for example, as the Grove—is very great. It is possible to work 40 or 50 wires out of a single Grove Battery of 50 cells. Mr. Haskins would hardly be willing to enter into a contract to run a separate battery of the same kind on each of these wires for the same price that he would the single one, supposing the other party to furnish the batteries and he the supplies and material consumed, to say nothing of the labor. The less the local action, however, the more nearly the statement becomes true. In a carefully tended Gravity Battery the loss from local action is very small.

The second chapter is devoted mainly to the subject of galvanometers. It contains cuts and descriptions of the tangent instruments of Bradley and Gaugain, and the "Universal" instrument of Dr. Siemens, together with an explanation of the principles of the bridge system of measurement, as employed in the last named apparatus, and also used in that of Gray & Barton, designed by Mr. Summers. The principle of the differential and of the sine galvanometer are explained, and full and explicit directions for the use of the different instruments are given.

The third and last chapter is devoted entirely to formulæ and tables, and is the part that will, of course, be most useful to the practical electrician. Several methods of ascertaining the constants of batteries, *i. e.*, their electro-motive force and internal resistance, are given, among them the beautiful method of Mance, and modification of the same by Sir Wm. Thomson, by means of which the resistance of a galvanometer may be found by the deflection of its own needle, and which will be new to most American electricians. There is an error of oversight on page 34, which should be corrected in an *errata*, as it is calculated to mislead an inexperienced person. In taking the internal resistance of a battery by the method most commonly employed, the student is directed to "halve the deflection by introducing resistance," whereas he should, of course, halve the tangent or sine of the deflection, as the case may be. Halving the deflection merely would give erroneous results if it were greater than 20 deg., and with a high deflection the error would be very great.

Most of the tests given are of course collected from the standard works on electricity, and arranged for convenience of reference. There are a number, however—some of them very useful and convenient ones—that have never found their way into print before, that we are aware of; among these are the author's method of separating the insulation resistance of two different portions of the same line, Mr. Varley's formula for the same, and Mr. Pope's method of measuring the conductivity of a line by the tangent galvanometer without opening the circuit, and from a way station. There is also a new and good formula for correcting the apparent insulation resistance of a leaky line, which is alone worth the price of the book. Sargent's formula for locating a cross by the Siemens galvanometer is published in this book for the first time, and is very ingenious.

The tables comprise units of measurement; diameter, weight, conductivity and resistance of iron and copper wires, weight of insulated office wire; electro-motive force of batteries; also sines, tangents, squares, cubes, square roots, cube roots and reciprocals, etc. A valuable original table, prepared by Dr. E. A. Hill, gives the weight and resistance of copper, iron and German silver wires of all diameters, from 1 to 200 miles, which electricians will find very convenient for many purposes. We would suggest that it would be well, in a future edition, to give the table accompanying the Siemens galvanometer, as a matter of convenience to the large number of electricians using that excellent instrument.

The publisher deserves the highest praise for the manner in which he has performed his part of the work. The type is clear and distinct, the paper excellent, and the binding neat and durable. Above all, the proof-reading seems to have been done with great care. The blank leaves supplied at the end of the book will be found very useful for noting down new formulæ as they may from time to time be brought to notice in the telegraphic journals.

We hope this excellent little work will meet with the sale its merits entitle it to. To every telegrapher who owns or uses a galvanometer, or ever expects to, it will be quite indispensable. The favor with which practical works of this kind are received is one of the most encouraging signs of modern telegraphic progress.—*The Telegrapher.*

STATISTICS OF THE MINES AND MINING IN THE STATES AND TERRITORIES WEST OF THE ROCKY MOUNTAINS. By ROSSITER W. RAYMOND, United States Commissioner of Mining Statistics. For sale by Van Nostrand.

The volumes before us form valuable supplementary matter to the former report of Mr. Raymond, that he entitled "Mines and Mining of the Rocky Mountains, the Inland Basin and the Pacific Slope," which appeared in the year 1870. They treat on the statistics and state of the mining industry in the States and Territories of California, Nevada, Oregon, Idaho, Montana, Utah, Arizona, New Mexico, Colorado, and Wyoming, with such information added and hints thrown out as are likely to be of use to miners, metallurgists, capitalists, and legislators. The advantage

of such reports is, that they bring the collective experience of miners and metallurgists together in a reliable and condensed form, so that it can be seen at a glance what processes are still in use and what have been superseded or rejected as useless, thus saving a waste of time in experimenting, and tending to make mining a permanent industry, more certain in its character and less speculative than in years gone by. The great difficulty in working many American mines at a profit arises from the dearness of labor, which it is probable may be solved in time by the Chinese; if they are properly managed, they make good and conscientious workmen, quick at learning and easily trained into skilled miners, though quite aware of their own value when they become so; yet the employment of them will tend to equalize wages, and enable many owners to work mines at a profit which cannot be worked now except at a loss. Mr. Raymond, speaking of the Chinese, says they show individual character just as other people do, and treating them all alike is a measure of ignorance fatal to successful management; the drawback to the employment of them is that they will never wait any time after their pay is due, and do not appear to acquire confidence in their employers in this respect, even after long service. Another obstacle to their exclusive employment is the frequency and length of their religious holidays, when they leave a mine *en masse* for a week at a time. Their great superiority over European miners is their fidelity to their bargain; they can be left to their work, and need no watching, as the latter do, but labor as consientiously as they would if they were closely watched. It seems a pity that the Government of the United States should vote such a small sum for the compilation of these statistics as $10,000. Mr. Raymond estimates that the smallest sum for which the business of collecting them could be properly conducted would be more like $25,000. As it is, voluntary correspondents have to be employed, and the information they send must be taken as received, without criticism or stricture, which is not so satisfactory as the employment of paid agents, who would be more under supervision and control. It is to be hoped that Congress may be induced to see this matter in the same light as their Commissioner, if only for the sake of the national honor; as the independent testimony of a Government mining official, as found in these reports, would in many instances prevent the foisting of worthless mines on European capitalists, or the stocking them on this side the water at such fabulous amounts that a five per cent. dividend might be looked upon as almost a miracle.—*Trubner's Literary Record.*

RESULTS OF AN EXPERIMENTAL INQUIRY INTO THE MECHANICAL PROPERTIES OF STEEL. By DAVID KIRKALDY. London: Testing and Experimenting Work, Southwark street. 1873.

The mechanical properties of steel of different degrees of hardness, and under various conditions, manufactured by Mr. Christian Aspelin, of the Westanfers and Fagersta Works, Sweden, were tested by Mr. Kirkaldy, under his own suggestions and conditions, for the purpose of exhibition at Vienna, where an extensive series of them was sent; and the results are here tabulated with illustrative diagrams. These results were obtained as the most likely to interest and to be of most general use to civil, mechanical, mining, and military engineers, and to be of importance to manufacturers of steel and iron. One series were prepared for, and sent first to, the Paris Exhibition of 1857. Another series are entirely new, and exhibited for the first time. None of those tested have been withheld.—*Builder.*

PRINCIPLES OF DECORATIVE DESIGN. By CHRISTOPHER DRESSER, F. L. S., etc. London and New York: Cassell, Peter & Galpin. For sale by Van Nostrand.

The object of this author has been to aid the art education of those who seek a knowledge of ornament applied to industrial purposes.

The substance of the present work was embodied in a series of articles in the "Technical Educator," where they were directed especially to those artisans who have daily to deal with the principles of decoration, and who have unfortunately been unable to obtain a paper education for their work.

Many beside artisans or artists, however, may reap substantial benefits from this timely work.

The book is a thin quarto, with nearly two hundred fairly executed illustrations.

NOTES ON A METALLURGICAL JOURNEY IN EUROPE.—By JOHN A. CHURCH, Engineer of Mines. New York: D. Van Nostrand. 1873.

The best information we can give of this new book is that afforded by the explanation in the author's preface, except that we may properly urge that a technical description of European metallurgical processes by so competent an observer must certainly abound with information which American mining engineers cannot well afford to overlook.

"The Notes which form the basis of the few papers that make up this book were taken solely for private use, and there was no intention of making them public until after the lapse of a considerable time. Their publication was then undertaken, not because they presented descriptions of novel processes, but because the author found that the poverty of English technical literature in this branch of industry was such as to be a serious annoyance to men engaged in the treatment of American ores. They first appeared in the columns of the "Engineering and Mining Journal," and their reception has been sufficiently favorable to warrant this republication.

"It is frequently said that American genius can be trusted to devise its own processes, and need not go abroad for instruction; but no one who is acquainted with the industry, skill and devotion of European metallurgists to their work can be willing to lose the fruits of their experiment and thought. Few persons know how much labor and money are spent by them every year in the work of revising old-established processes, both by laboratory examination and by experiments conducted on the largest scale."

The two years that elapsed between the author's journey in Europe and the publication of these Notes was sufficient to bring about such changes and improvements in foreign practice that he could no longer rely upon the details of his work, but was obliged to collate it with the latest technical publications abroad. He is therefore indebted to many writers, and has endeavored to

properly express this fact in foot-notes to each paper. But he has not described any works that were not visited and carefully studied by him, and trusts that the personal knowledge thus gained has enabled him to appropriate with success and incorporate with his own the work of others.

A Treatise on the Richards Steam Engine Indicator. By Chas. T. Porter. With large additions, by F. W. Bacon, M. E. New York: D. Van Nostrand. 1873.

This newly revised edition of a well known and widely useful book will doubtless be gladly received by the engineering profession.

The examples and rules added by the American editor were in the older edition of great value to practical engineers. The new additions, including as they do results of the most recent experiments of a veteran in this field of labor, will prove invaluable to the learner.

Mr. Bacon's mature judgement, ripened by many years' labor among steam engines, gives a weight to his instructions which his co-laborers already know how to value.

MISCELLANEOUS.

The Great Bell at Mengoon, Upper Burmah.—This bell is said to be the largest and heaviest in the world, except the Cathedral bell of Moscow. From the lip to the top of the shackle it measures 20 ft.; at the lip, which is its largest diameter, it is 16 ft. 4 in. inside; at the height of 5 ft. 9 in. from the lip, it is 10 ft. in diameter; and at the top, inside, it is 7 ft. 11 in. The metal —cast iron—of which the shackle is composed, is 21 in. in diameter. Two griffins are cast solid on to the top of the bell, and between them the eye is formed for the pin which connects the shackle, and by which the bell is suspended. It stands on a low terrace, on either end of which two brick and mortar piers are built. The piers enclose massive teak wood frames, which give strength to the whole structure. Three wooden beams are laid across from pier to pier, and the bell swung free between them till an earthquake occurred in 1839, which shook the piers, when it was found necessary to put wooden supports underneath to carry the weight; so it does not now swing free, and consequently emits no sound. The weight of the bell, pin, and shackle altogether is about 90 tons, and, with the very rude appliances the Burmese have for engineering of any kind, it is an astonishing piece of work.

Casting the Standard Metre.—An important step has been taken in the carrying out of the decisions of the international Metric Commission which met at Paris in October last year. The form and mode of execution of the standard metre having been settled, the Commission intrusted to the French section the manufacture and comparison of the new metres with the original standard in the archives of France. We learn from "Les Mondes" that before proceeding to cast the definitive metres, the French Commission has thought it advisable to execute the first types, with which to test successively all the methods that will ultimately be applied to the definitive metres. The first experiment took place in the laboratory of M. H. Sainte-Claire Deville, who, with the assistance of M. Debray, has succeeded in obtaining the iridio-platinum alloy perfectly pure. The operation of casting this first international metre was considered of so much importance that the President of the Republic and some of his Ministers, and other eminent Frenchmen, "assisted" at it. Nine kilogrammes of platinum, with one kilogramme of iridium, were melted under the action of the oxhydrogen flame from a blowpipe in three quarters of an hour. The ingot was then cast, perfectly limpid, in a mould formed, like the furnace itself, of a block of carbonate of lime, whose interior walls alone were burned under the influence of the excessive temperature which was developed; consequently with this substance there is no risk of breakage. The metal was allowed to cool in the mould, and preserved its bright surface; in this condition it will be submitted to all the processes necessary to give it the definitive form which it ought to possess. The operation was considered, by all who witnessed it, as perfectly successful. *Engineering and Mining Journal.*

Zincing Iron.—The following is an excellent and cheap method for protecting iron articles exposed to the atmosphere, such as cramp irons for stone, etc., from rust: They are to be first cleansed by placing them in open wooden vessels, in water, containing three-fourths to one per cent. of common sulphuric acid, and allowed to remain in it until the surface appears clean, or may be rendered so by scouring with a rag or wet sand. According to the amount of acid, this may require from 6 to 24 hours. Fresh acid must be added according to the extent of use and of the liquid, and when this is saturated with sulphate of iron, it must be renewed. After removal from this bath, the articles are rinsed in fresh water, and scoured until they acquire a clean metallic surface, and then kept in water in which a little slaked lime has been stirred, until the next operation. When thus freed from rust they are to be coated with a thin film of zinc, while cold, by means of chloride of zinc, which may be made by filling a glazed earthen vessel, of about two-thirds gallon capacity, three-fourths full of muriatic acid, and adding zinc clippings until effervescence ceases. The liquid is then to be turned off from the undissolved zinc, and preserved in a glass vessel. For use it is poured into a sheet zinc vessel, of suitable size and shape for the objects, and about 1.30 per cent. of its weight of finely powdered sal ammoniac added. The articles are then immersed in it, a scum of fine bubbles forming on the surface in from one to two minutes, indicative of the completion of the operation. The articles are next drained, so that the excess may flow back into the vessel. The iron articles thus coated with a fine film of zinc are placed on clean sheet iron, heated from beneath, and perfectly dried, and then dipped piece by piece, by means of tongs, into very hot, though not glowing, molten zinc, for a short time, until they acquire the temperature of the zinc having been cleaned with an iron spoon. They are then removed and beaten, to cause the excess of zinc to fall off.